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TP 7423

EVALUATION OF SELECTED CONTAINERS USED FOR THE SHIPMENT OF DANGEROUS GOODS

DECEMBER 31, 1985

Transport Dangerous Goods Directorate

Direction générale du transport des marchandises dangereuses

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PREFACE*

This study was carried out at the Ontario Research Foundation by W. Soroka and G. Wallace under DSS contract 17SV T8080-3-1279 for Transport Canada. The technical coordinator for Transport Canada Transportation of Dangerous Goods was J.J. LeBlanc.

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* La préface, le résumé, la table des matière et le sommaire du présent rapport sont également disponibles en français. Pour en obtenir une copie, communiquez avec la

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ABSTRACT

This study was carried out to establish the actual performance capabilities of selected packages in use for the Transport of Dangerous Goods. The performance characteristics of selected 208L steel and plastic drums, selected 20L steel and plastic pails and a corrugated fibreboard container were established, using current performance evaluation methods specified in Canadian Transport Commission Regulations (equivalent to US DOT Regulations) and UN Recommendations. Approximately 120 replicates of each sample were tested. The average drop height and hydrostatic pressure capability, at failure, were determined. Tests in accordance with ASTM D4169 at level 1 and 2 were also carried out. Many of the tested containers did not meet the performance test requirements established in Regulations.

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SUMMARY

The performance characteristics of selected 208L steel and plastic drums, selected 20L steel and plastic pails and a corrugate container have been examined using current performance evaluation methods.

It has been statistically established that many of the tested containers will not meet current packaging group 2 dangerous goods requirements as described in U.N. recommendations or current C.T.C. (D.O.T.) requirements. In some instances packagings will not qualify as U.N. packaging group 3 containers. This data, along with observations of failure modes, is discussed in the report.

The test methodologies used for determining performance level, specifically drop testing and testing in accordance with A.S.T.M. D4169 were examined. The Bruceton "staircase" method of drop testing was highly successful in quantifying drop test results and is recommended for broader application. A.S.T.M. D4169 methods, while conceptually attractive, require considerable more study and adjustment before they can be used as a regulatory performance test.

Work with vibration tests, while limited, has shown that there is some question regarding the co-relation of these tests with actual field experience.

A preliminary analysis of ride data, collected from instrumented container and trailer on flatcars travelling from Toronto to Vancouver is discussed.

The report provides a discussion of topics for further work in this field.

1. INTRODUCTION

This report describes a comprehensive performance evaluation program of selected containers used for the transport of dangerous goods. The principle objective of this program was to establish the actual performance level of selected containers when tested by methods commonly specified in dangerous goods code regulations.

Further objectives of this program were as follows:

- Examine the suitability of A.S.T.M. sequence testing methods as applied to dangerous goods containers.

- Examine any available field failures available during the course of this project

- Investigate actual distribution environment conditions where the opportunity becomes available during the course of this program.

2. TEST SPECIMENS AND REPORTING

Test specimens were procured from various manufacturers from both Canada and United States in quantities sufficient to provide for a statistically valid testing program. For the purposes of this report, specimens are referred to by a manufacturer's letter code assigned to the container upon receipt at Ontario Research Foundation (ORF).

3. TEST PROCEDURES

3.1 Reference Documents

Test methodologies were designed to be consistent with the intent of:

1. C.T.C. "Regulations for the Transport of Dangerous Commodities by Rail".

2. United Nations, "Transport of Dangerous Goods, Recommendations of the Committee of Experts on the Transport of Dangerous Goods", Third Revised Edition.

3. A.S.T.M. D4169-82, "Recommended Practice for Performance Testing of Shipping Containers and Systems".

The technique for determining mean drop test passing heights, occasionally referred to as the Bruceton or staircase method, is described in:

M.G. Natrella, Experimental Statistics, Handbook 91, United States Department of Commerce: Chapter 10, Sensitivity Testing, (Appendix 1).

3.2 Specimen Preparation

Each container was sequentially numbered prior to testing.

Tare and 100% capacity masses were established for all water filled containers. One hundred percent capacity was taken as that level of water that would rise slightly up the pour opening. For pails, this level was taken before insertion of the pour spout. For open head containers the level was taken as that point at which the water is in total contact with the lid.

Two percent of the total water mass was then subtracted to provide a 98% capacity fill mass. Unless specified otherwise, this fill level was used for all test procedures.

Pour spouts, closures and lids were applied using standard production equipment and procedures, and in accordance with the respective supplier's instructions.

All water filled containers were allowed to come to ambient temperatures prior to testing.

3.3 Drop Testing

Drop testing procedurres met the intent of both U.N. and C.T.C. (D.O.T.) requirements, excepting for selection of drop heights. All drums and pails were dropped diagonally in a "corner over corner" configuration. Various grips, fixtures and slings were used to achieve this orientation, depending on the container being tested.

Mechanical release devices were used to release the test container without imparting rotation or other movement (photographs 1 and 2). The impacting surface was concrete.

Drop test height was determined according to the "staircase" or "Bruceton" method and typically started at 1.2m. Drop test increments of 0.2m were used for 208L drums, and 0.1m for 20L pails. Each drop test was conducted from one test increment above or below the previous test level, depending on whether the previous test was a pass or a failure. (Other incremental variations were used during early stages of the program to develop the methodology. Calculations for mean and standard deviation using "staircase" data take test increments into account and the data is still valid though not appearing as neat).

In some instances, several drops at increasing heights were required before a failure was registered. The calculation of mean and standard deviation values from staircase results uses data from one test increment below the first observed failure, and up to the value where all tests are failures. Data above or below these points is discounted, and therefore have no effect on the calculated mean, other than reducing the effective sample size.

Photograph 1

Photograph 2

Photographs 1 and 2, Quick release devices used to provide a non-rotational drop for drums (left) and pails (right)

Drums and pails were vented immediately after impact either by relieving the closure, or where this was awkward, by producing a hole at some upper and unaffected part of the container.

Each drop tested container was observed for a period of 10 minutes. If no free-falling water droplets were observed in this time, the container was judged to have passed the test.

Corrugate containers were dropped using a cantelevered arm drop test apparatus. The drop test procedure met the intent of A.S.T.M. D775-80, "Drop Test for Loaded Boxes".

3.4 A.S.T.M. D4169, Performance Testing

For comparative purposes, selected containers were evaluated for performance in accordance with American Society for Testing and Materials (A.S.T.M.) standard practice for "Performance Testing of Shipping Containers and Systems" designation: D4169. Distribution Cycle 1, "General schedule, undefined distribution system" was used.

Briefly, containers were tested sequentially according to the following schedule:

- One flat bottom drop from specified height. (208L drums were tilt dropped).
  Two flat side drops, 90 degrees apart, from specified height.
  Two diagonal bottom edge drops, 90 degrees apart, from specified height.
  One top drop from specified height.

- Compression loaded to the specified level and immediately released.

- Vibration test at 0.5g and sweeping at 1/2 octave/min. from 3 Hz. to 100 Hz., with specified dwells at each resonance point. Drums were top loaded with a mass equal to the drum being tested.

- Repetitive shock for specified time at 25.4mm double amplitude and 1.1g acceleration.

- Simulated rail switching using a specified velocity and a 40 ± 10ms shock pulse. One similar drum or two pails were used as backloading. Each test container was impacted three times.

- Repeat of complete drop test cycle as described above.

Test levels were as follows:

Element	1	2	3
Handling (drop) (ASTM D997 or ASTM D1083)	pails 457mm (18") drums 229mm (9")	305mm (12") 152mm (6")	178mm (7") 76mm (3")
Vehicle Stacking	pails 337kg (742 lb) drums 1364kg (3000 lb)	225kg (495 lb) 909kg (2000 lb)	169kg (371 lb) not tested
Stacked Vibration	15 min. resonance dwell	10 min. resonance dwell	5 min. resonance dwel
Loose Load Vibration (ASTM D999)	60 min.	40 min.	30 min.
Rail Switching (ASTM D880)	2 at 3.58 m/s 1 at 2.68 m/s	2 at 2.68 m/s 1 at 1.79 m/s	1 at 2.68 m/ 2 at 1.79 m/

3.5 Hydrostatic Testing

Containers were tested, filled with water, by raising the internal pressure at approximately 25 kPa per minute until failure was observed.

4. PERFORMANCE EVALUATIONS OF 208L STEEL DRUMS

4.1 208L, C.T.C. (D.O.T.) 17E Steel Drums, Drop Tests

Steel drums are required to be able to pass drop tests from the following heights:

To meet C.T.C. (DOT) 17E	To meet U.N. Recommendations
4 ft. (1.2m)	Packing group I - 1.8m
	Packing group II - 1.2m
	Packing group III - 0.8m

Drop test data are summarized in Table 1.

					Failing Drop Height	
Code	Seam	Drop Orientation	Total Dropped	Total Failed	Calculated Mean	Calculated Std. Deviation
C	d	Bottom	50	26	1.09	0.36
C	d	Top	50	26	0.83	0.40
D	t	Bottom	51	16	4.47	1.17
D	t	Top	50	22	2.13	0.77
E	d	Bottom	50	22	1.93	0.55
E	d	Top	50	26	1.12	0.55
F	t	Bottom	51	20	2.95	0.84
F	t	Top	50	25	1.03	0.32
M	d	Bottom	50	25	1.33	0.33
M	d	Top	50	24	1.62	0.61
N	t	Bottom	53	18	4.33	1.22
N	t	Top	58	19	4.47	0.78
O	t	Bottom	50	24	1.65	0.31
O	t	Top	50	25	1.45	0.41

TABLE 1

Drop Test Data Summary - 208L Steel Drums

Graphic representations of the total drops for each drum type and orientation are given on pages 15 through 21.

A typical specimen laboratory record of a Bruceton Staircase drop sequence is provided in Appendix 2.

All drums had marks indicating conformance with either C.T.C. or D.O.T. 17E and that construction was 20 gauge steel bodies and 18 gauge steel heads.

Drum metal gauges were verified and are given in Table 2. Nominal and minimum metal thickness is given below for 18 and 20 gauge steel. (A metal thickness/gauge table can be found in Appendix 3).

Gauge No.	Nominal Thickness	Minimum Thickness
18	0.0478" (1.214mm)	0.0438" (1.087mm)
20	0.0359" (0.912mm)	0.0324" (0.823mm)

Drum Code	Top Head 1	Top Head 2	Top Head 3	Body 1	Body 2	Body 3	Bottom Head 1	Bottom Head 2	Bottom Head 3
C	.0462	.0463	.0468	.0345	.0353	.0335	.0466	.0461	.0470
D	.0463	.0463	.0466	.0341	.0331	.0338	.0478	.0474	.0463
E	.0468	.0469	.0467	.0341	.0345	.0349	.0468	.0466	.0474
F	.0473	.0465	.0464	.0346	.0346	.0344	.0461	.0468	.0469
M	.0449	.0458	.0445	.0371	.0374	.0371	.0452	.0463	.0456
N	.0456	.0452	.0455	.0335	.0338	.0335	.0480	.0466	.0469
O	.0418*	.0428*	.0415*	.0349	.0351	.0346	.0420*	.0422*	.0452

Sample No. and Metal Thickness (inches)

TABLE 2

208L Drum Metal Thickness Measurements

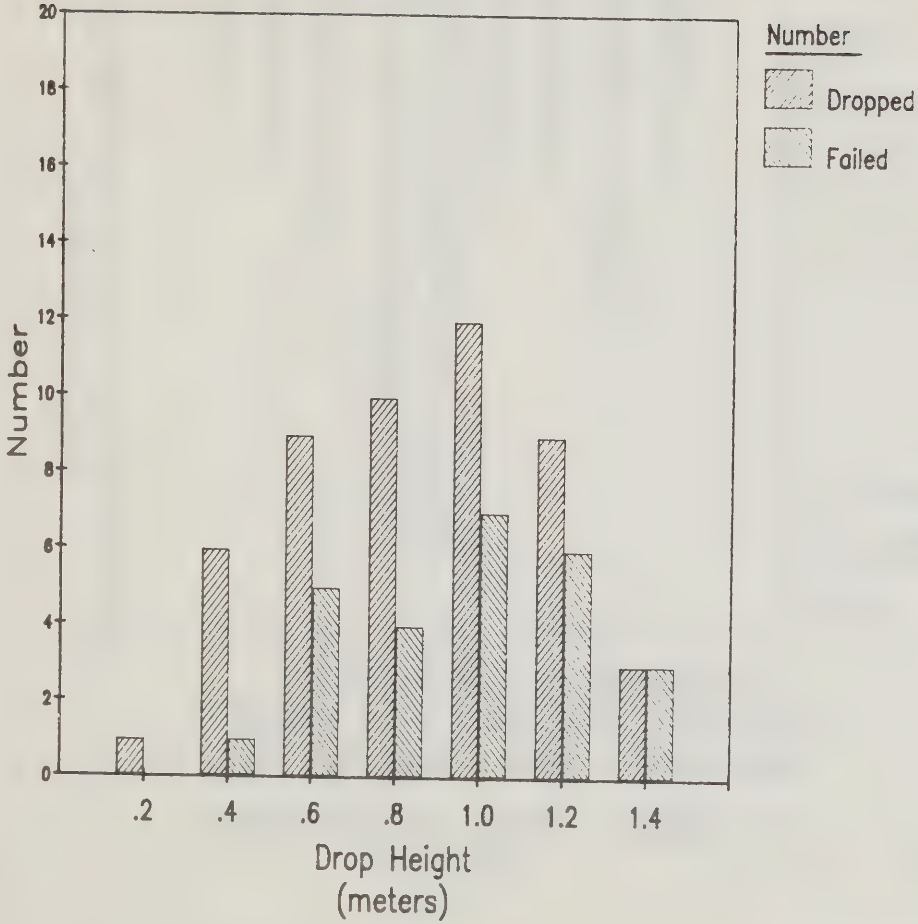
*metal thickness below specification

DROP TEST DATA, CODE: C

208L 17E Steel Drum, Double Seam

Orientation: Top Mean: 0.83m SD: 0.40m

No. Tested: 50 No. Failed: 26

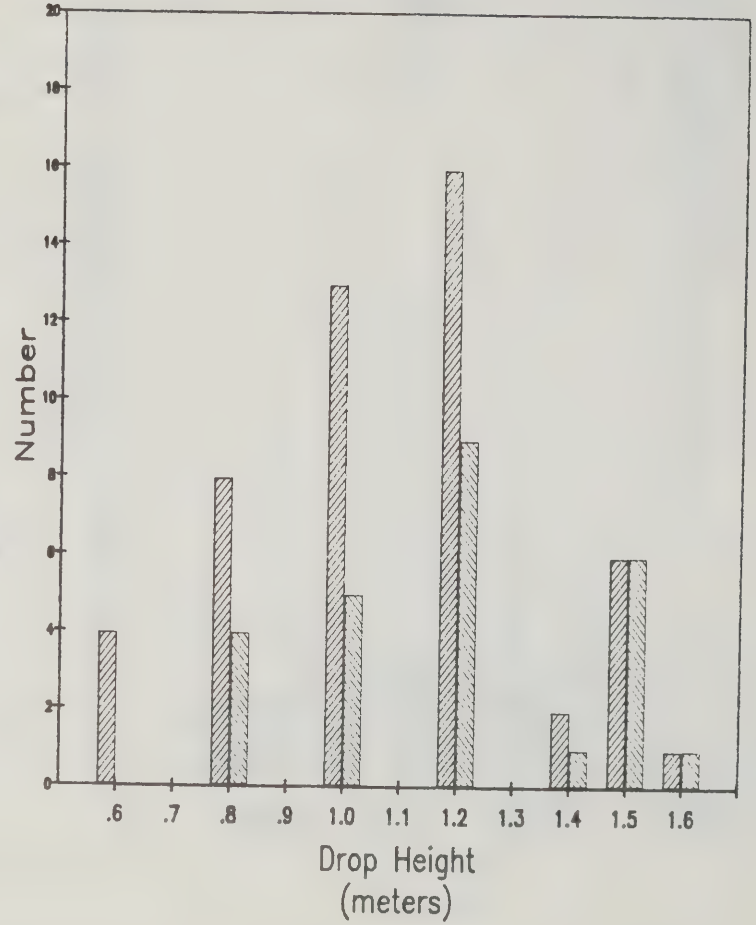


DROP TEST DATA, CODE: C

208L 17E Steel Drum, Double Seam

Orientation: Bottom Mean: 1.09m SD: 0.36m

No. Tested: 50 No. Failed: 26

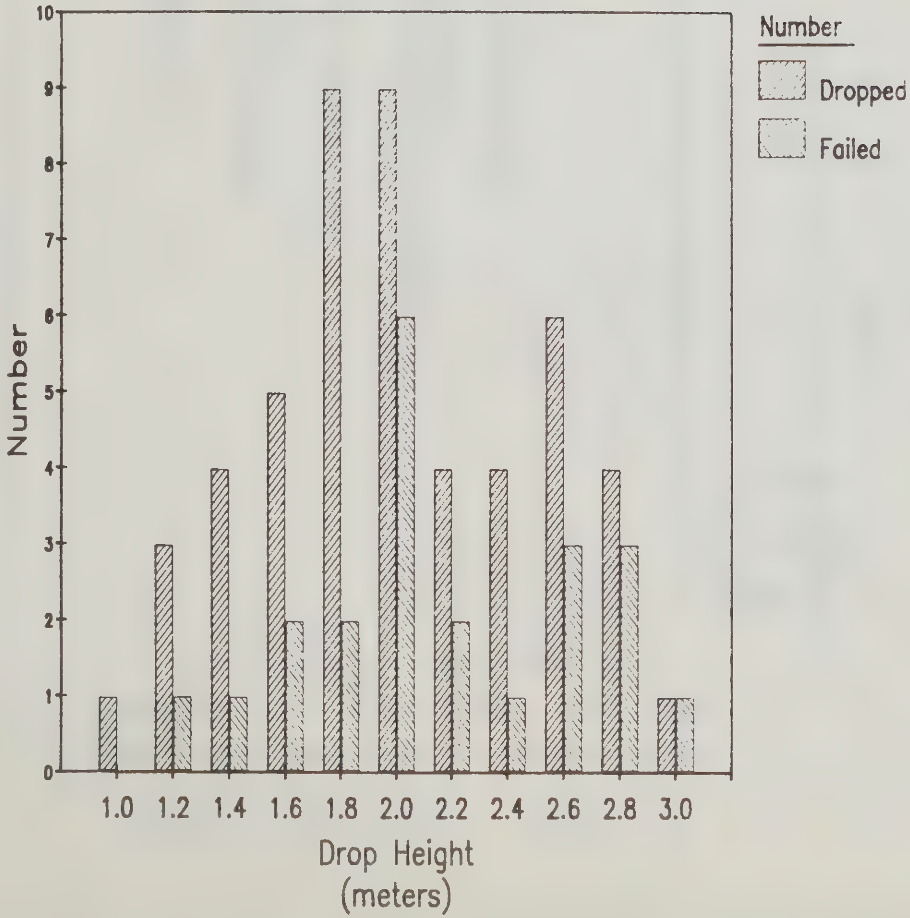


DROP TEST DATA, CODE: D

208L 17E Steel Drum, Triple Seam

Orientation: Top Mean: 2.13m SD: 0.77m

No. Tested: 50 No. Failed: 22

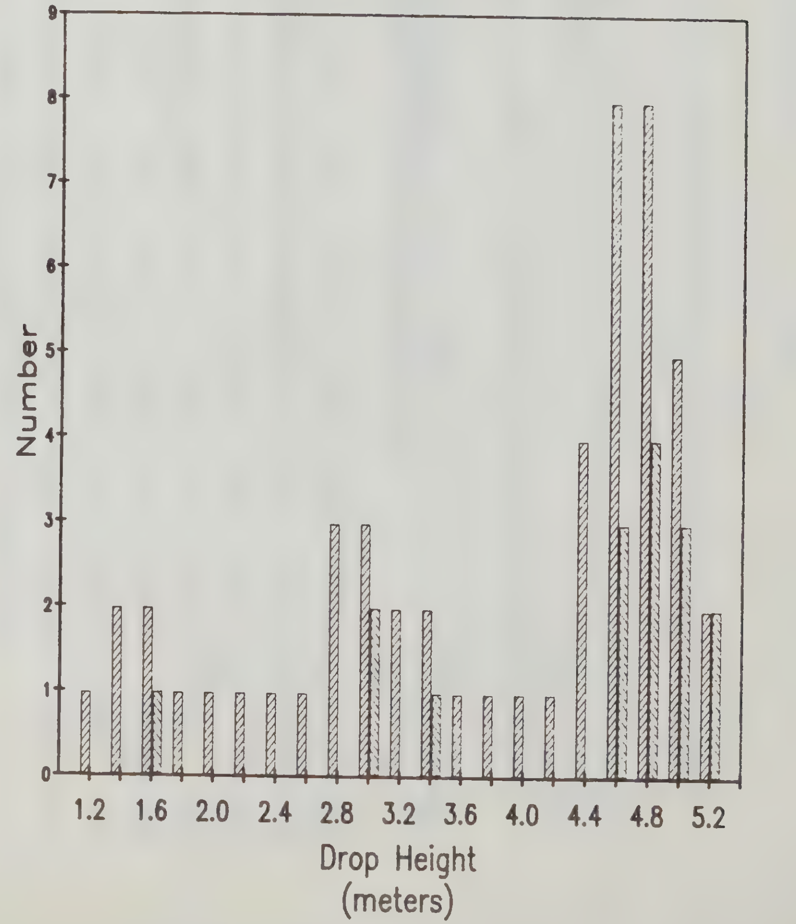


DROP TEST DATA, CODE: D

208L 17E Steel Drum, Triple Seam

Orientation: Bottom Mean: 4.47m SD: 1.17m

No. Tested: 51 No. Failed: 16

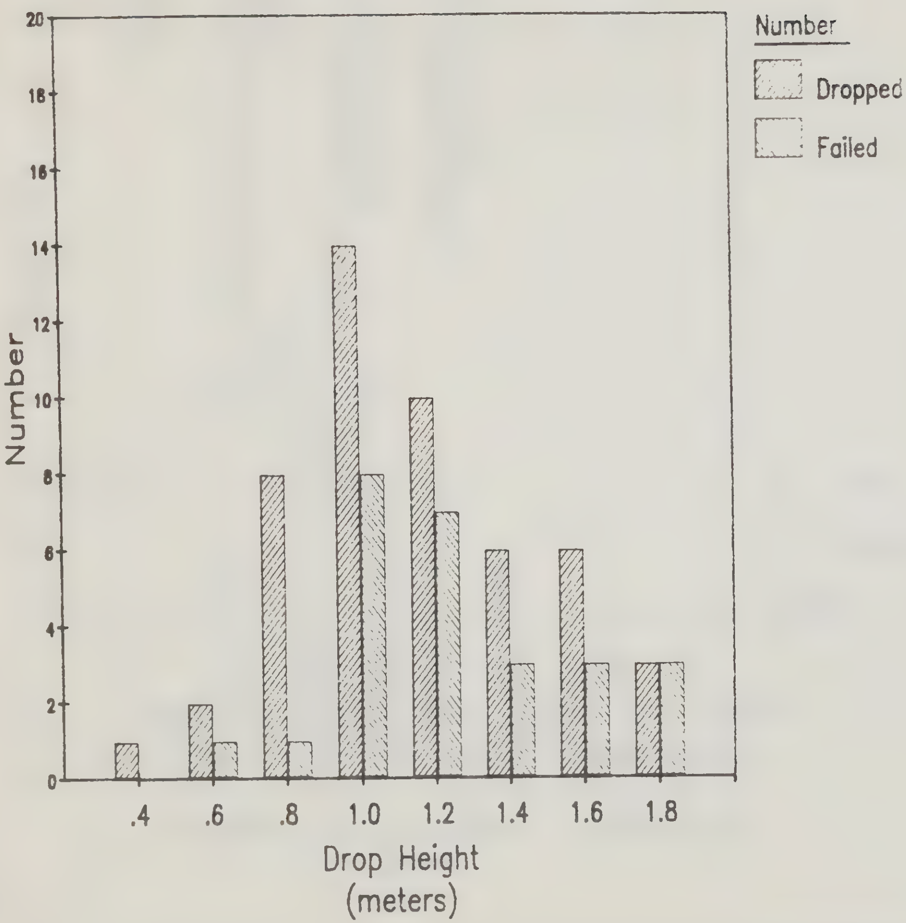


DROP TEST DATA, CODE: E

208L 17E Steel Drum, Double Seam

Orientation: Top Mean: 1.12m SD: 0.55m

No. Tested: 50 No. Failed: 26

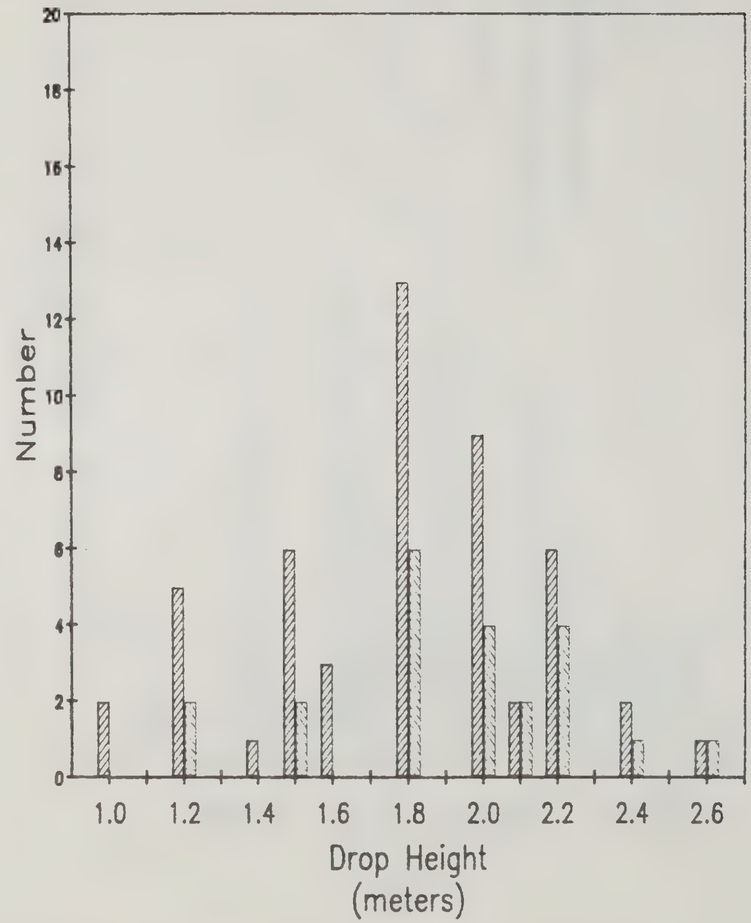


DROP TEST DATA, CODE: E

208L 17E Steel Drum, Double Seam

Orientation: Bottom Mean: 1.93m SD: 0.55m

No. Tested: 50 No. Failed: 22

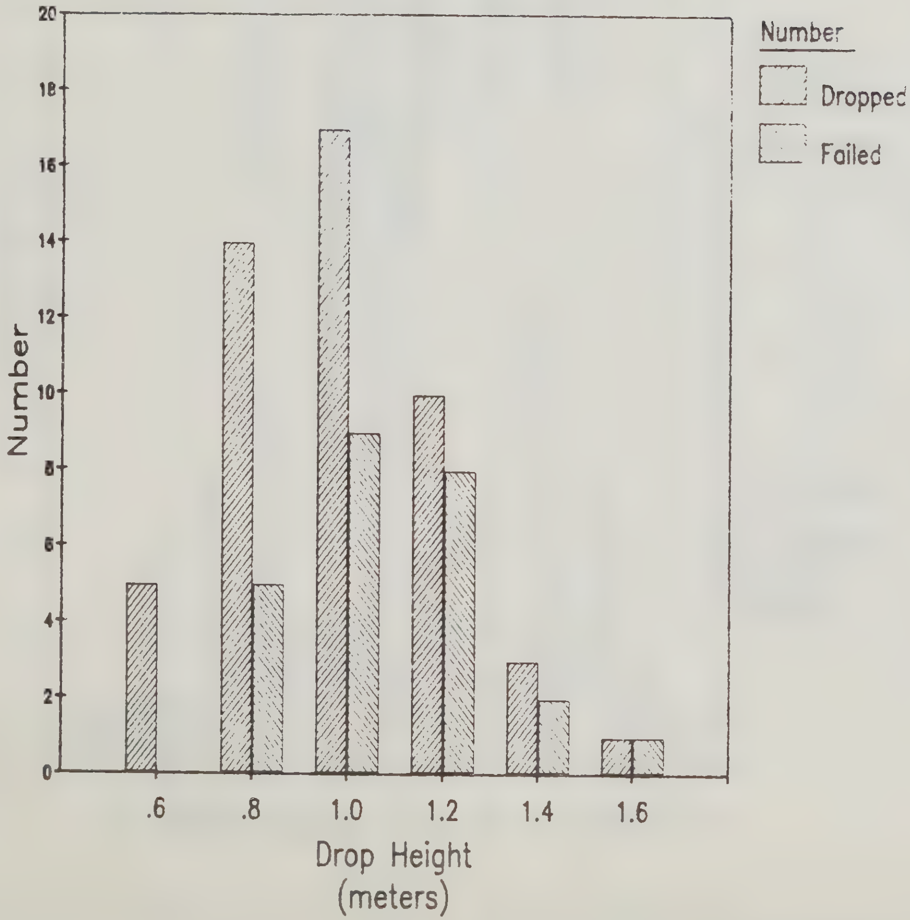


DROP TEST DATA, CODE: F

208L 17E Steel Drum, Triple Seam

Orientation: Top Mean: 1.03m SD: 0.32m

No. Tested: 50 No. Failed: 25

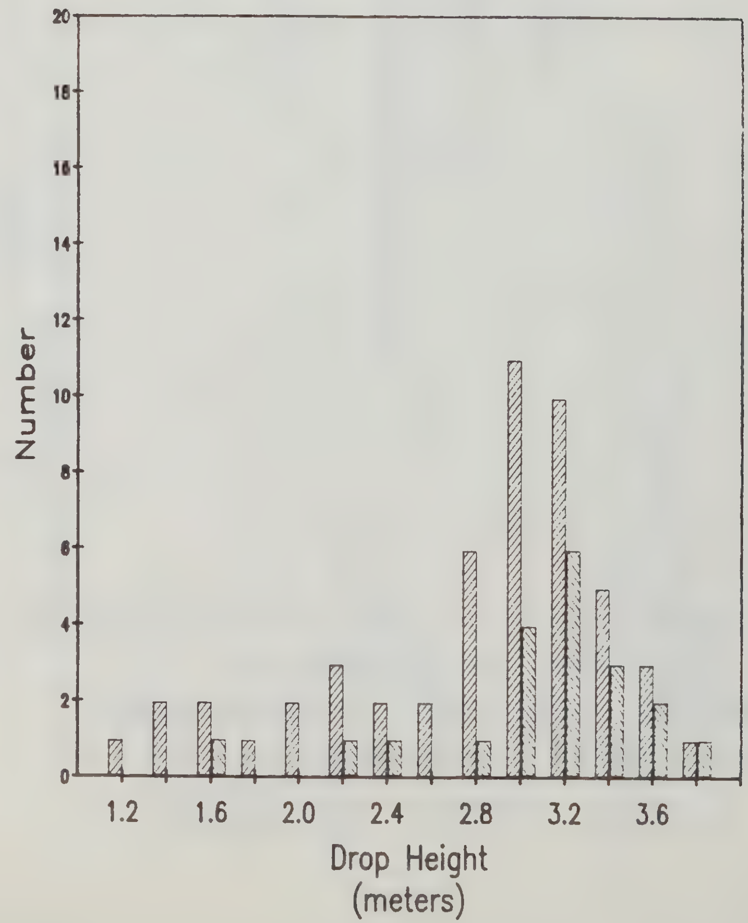


DROP TEST DATA, CODE: F

208L 17E Steel Drum, Triple Seam

Orientation: Bottom Mean: 2.95m SD: 0.84m

No. Tested: 51 No. Failed: 20

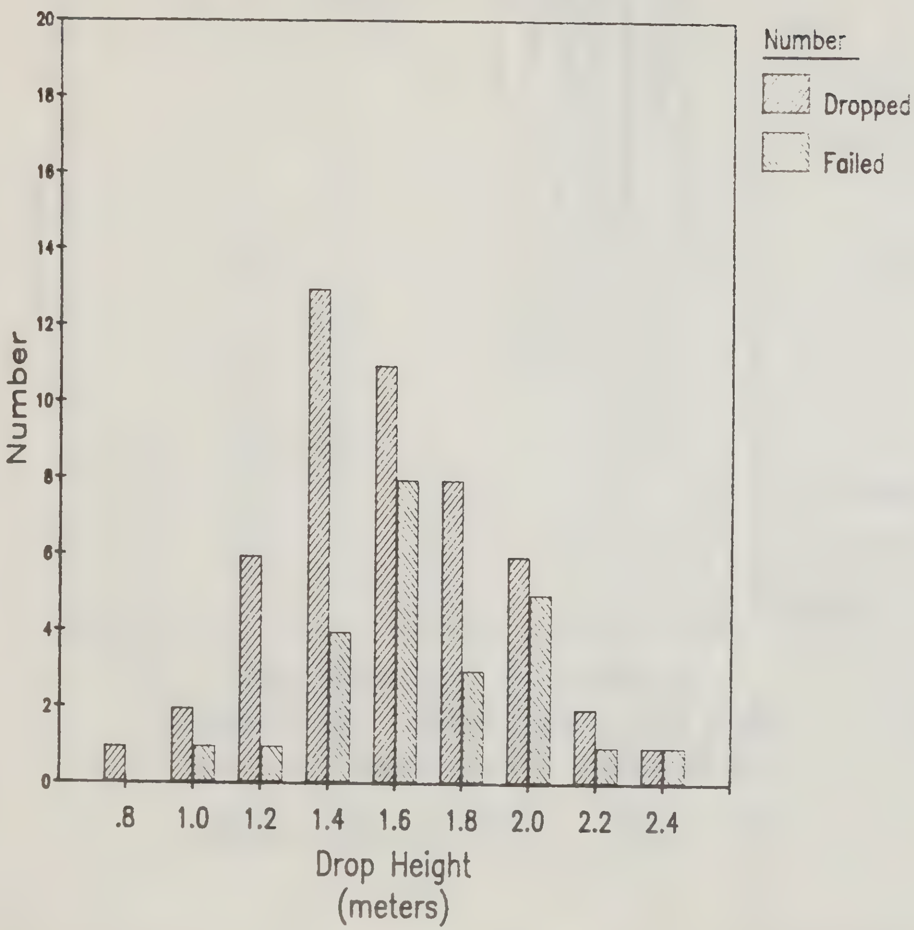


DROP TEST DATA, CODE: M

208L 17E Steel Drum, Double Seam

Orientation: Top Mean: 1.62m SD: 0.61m

No. Tested: 50 No. Failed: 24

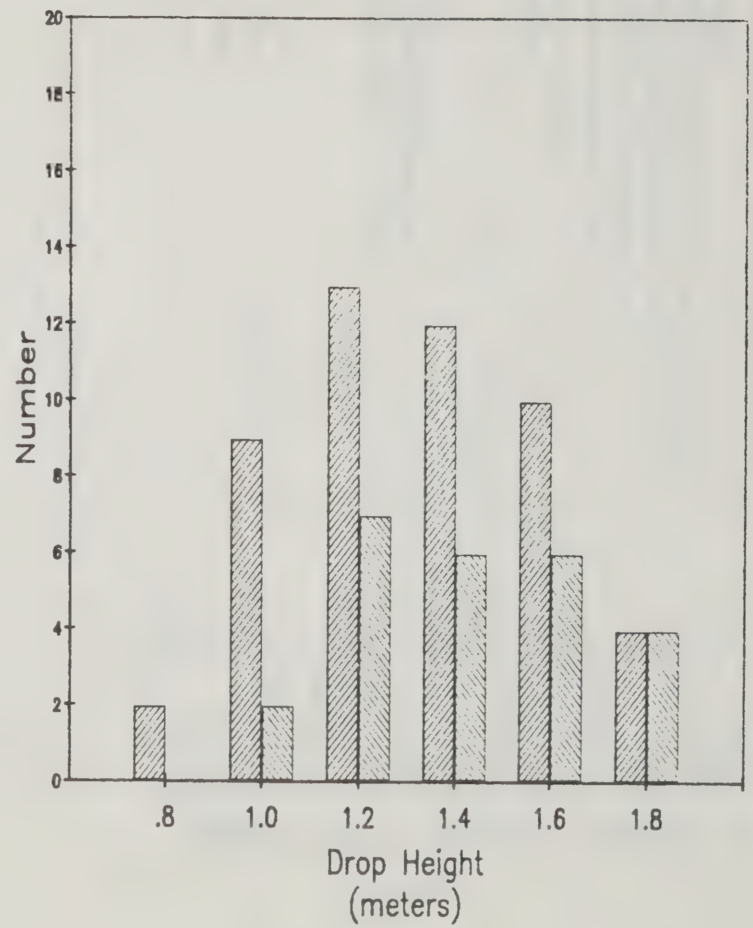


DROP TEST DATA, CODE: M

208L 17E Steel Drum, Double Seam

Orientation: Bottom Mean: 1.33m SD: 0.33m

No. Tested: 50 No. Failed: 25

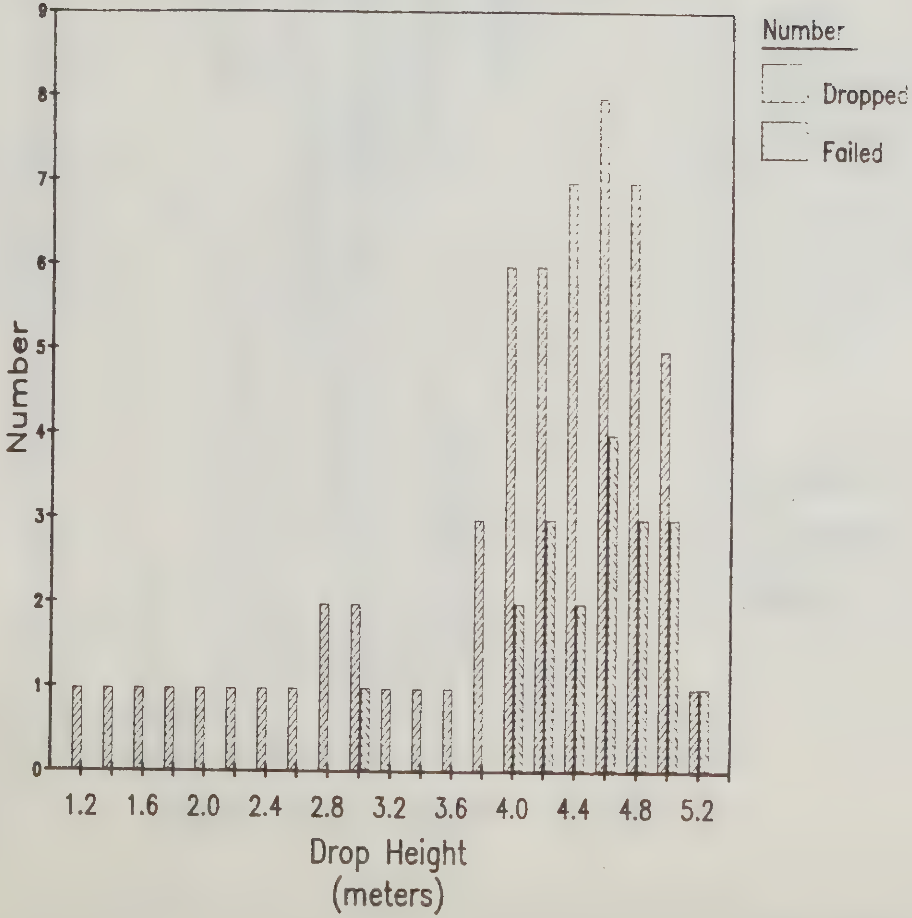


DROP TEST DATA, CODE: N

208L 17E Steel Drum, Triple Seam

Orientation: Top Mean: 4.47m SD: 0.78m

No. Tested: 58 No. Failed: 19

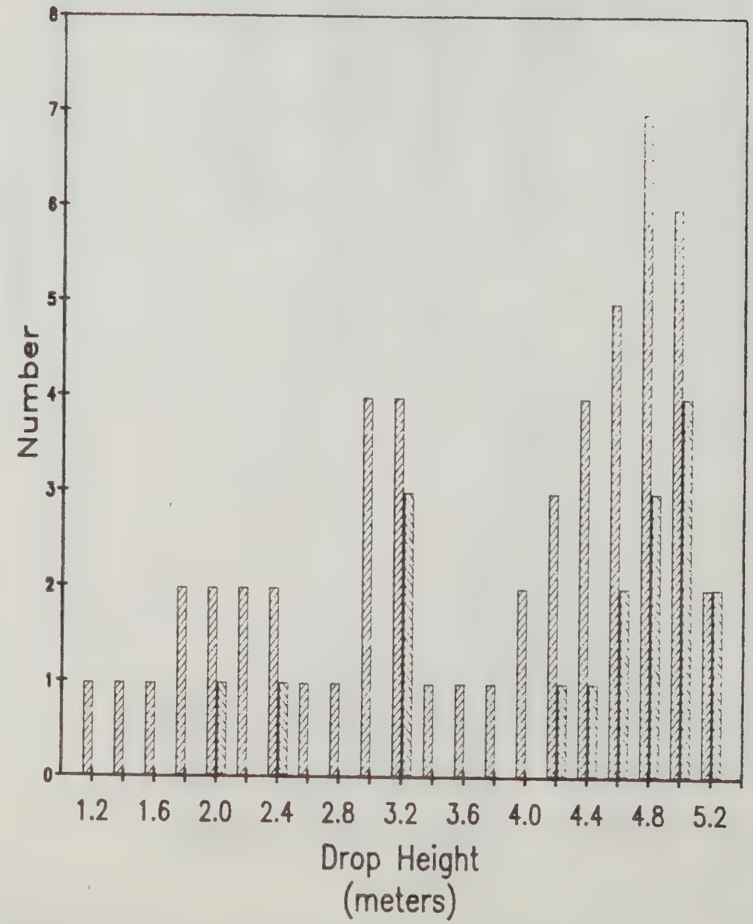


DROP TEST DATA, CODE: N

208L 17E Steel Drum, Triple Seam

Orientation: Bottom Mean: 4.33m SD: 1.22m

No. Tested: 53 No. Failed: 18

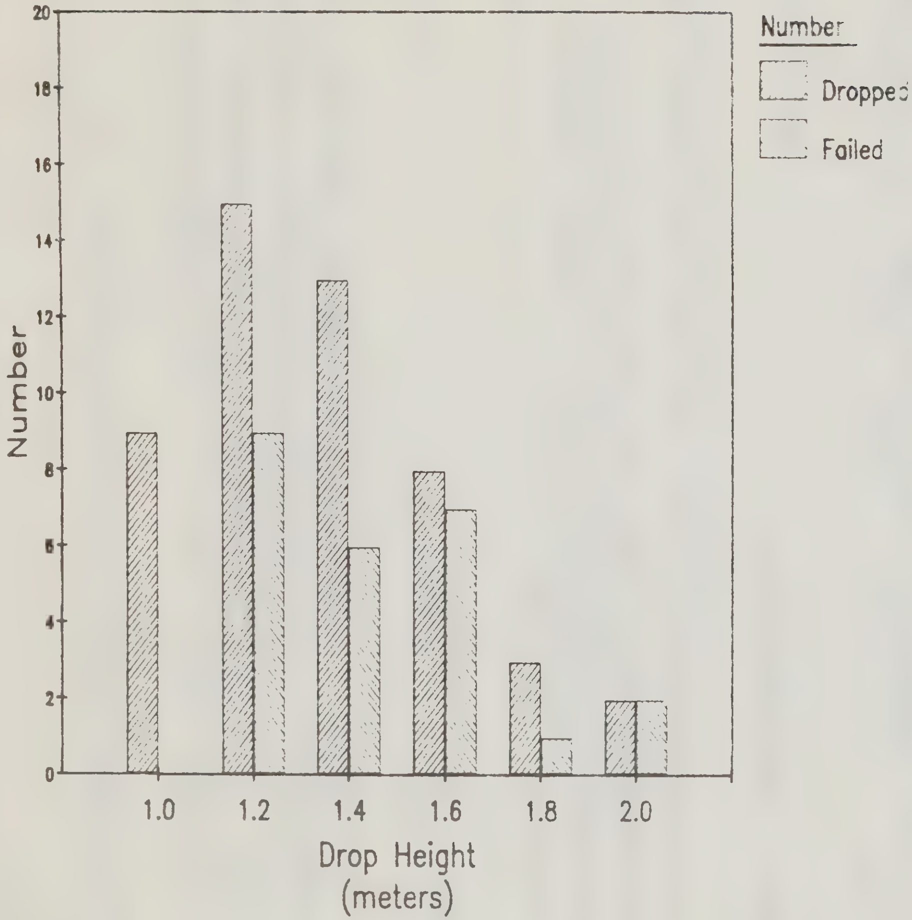


DROP TEST DATA, CODE: O

208L 17E Steel Drum, Triple Seam

Orientation: Top Mean: 1.45m SD: 0.41m

No. Tested: 50 No. Failed: 25

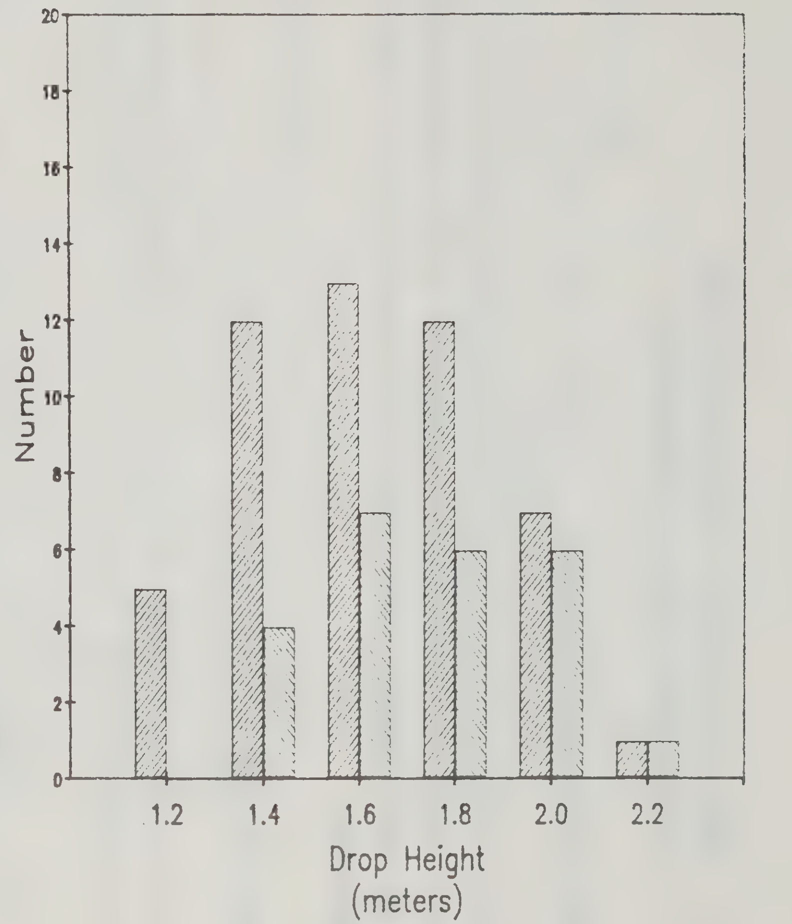


DROP TEST DATA, CODE: O

208L 17E Steel Drum, Triple Seam

Orientation: Bottom Mean: 1.65m SD: 0.31m

No. Tested: 50 No. Failed: 24



4.2 208L, C.T.C. (D.O.T.) 17E, Steel Drums, Miscellaneous Drop Test Observation

Code "C" 208L Double Seam

All leaks on both top and bottom drops were from the chime. The chime would appear to unroll or open and leak at these points. No side seam leakage, metal fracture or leaking past the bungs was observed.

Code "D" 208L Triple Seam

Of the 50 bottom drops, 1 failure was observed as a metal fracture in the bottom chime, and 3 were leaking from the top chime.

Of the top drop failures, 11 metal fractures or tears in the top chime were observed. All other failures were leaks past the top chime.

Code "E" 208L Double Seam

All leaks were from the chime on both the top and bottom drops. The chime would appear to unroll and leak at these points. Occasionally, as the drum would begin to leak, a white substance would precede the water.

Code "F" 208L Triple Seam

Of the bottom drop containers which leaked, 3 were metal fractures in the sidewall, 9 failures were metal fractures at the bottom chime. All others were leaks past the chime. The metal fractures in the chime varied in length from 50mm to 450mm around the chime.

All top drop failures were leaks past the chime.

Code "M" 208L Double Seam

All the bottom drop failures leaked at the bottom chime. One container was observed to leak at the intersection of the side seam and bottom chime. All top drop failures were observed to leak from the top chime.

Code "N" 208L Triple Seam

The bottom drop failures were all observed to leak from the bottom chime, with the exception of one container which had a break in the metal around the bottom chime.

Of the top drop failures, 11 containers leaked past the large bung, (between bung and flange) one container had a fracture in the metal around the top chime, and the remainder leaked past the top chime.

Code "O" 208L Triple Seam

All bottom drop failures were leaks past the bottom chime.

Two of the top drop failures were leaks past the large bung (between bung and flange), with the remainder of the failures being leaks past the top chime.

Failure Orientation

There was no apparent drop orientation relative to closures or side seam welds that was observed to produce greater numbers of failures. The side seam weld was not observed to be a vulnerable failure area for any drum tested.

Observations of Metal Fracture During Drop Testing

No metal fractures were observed for drum types C, E, M and O. Types D, F, and N (all triple seam types) exhibited some metal fracture as part of the failure mechanism.

A detailed listing of those drums exhibiting metal fracture after drop testing is given in Table 3.

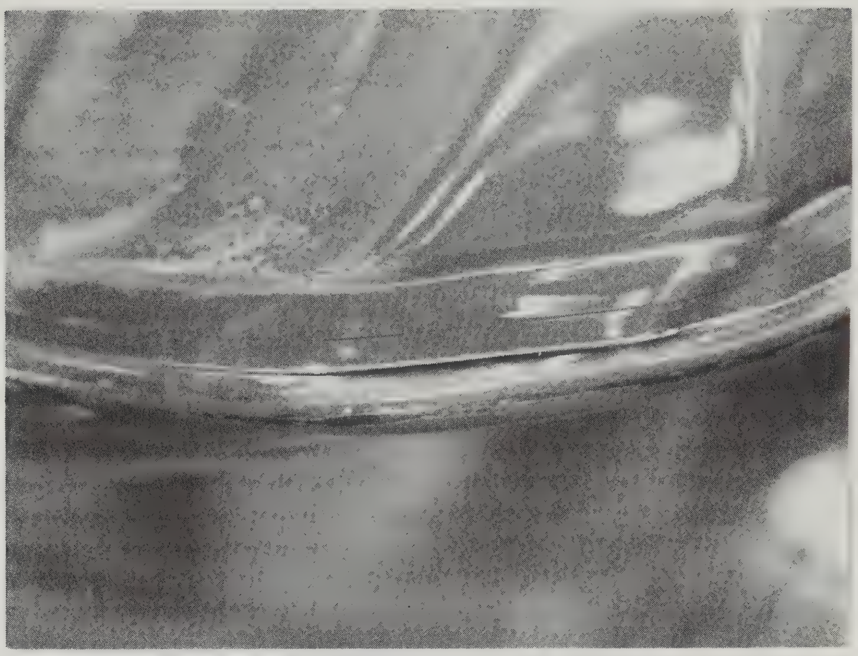
Drum Code	Drop Height	Observation
D	Bottom Drop	
	4.6 M	Tear at top chime
D	Top Drop	
	2.0 M	200mm tear, top chime
	2.0 M	200mm tear, top chime
	2.2 M	200mm tear, top chime
	2.0 M	150mm tear, top chime
	1.6 M	25mm crack, top chime
	1.6 M	200mm tear, top chime
	2.2 M	50mm tear, top chime
	2.4 M	50mm crack, top chime
	2.8 M	75mm crack, top chime
	2.8 M	150mm tear, top chime
	2.6 M	50mm crack, top chime
F	Bottom Drop	
	2.4 M	Tear in body near chime
	3.0 M	Tear in body near chime
	3.4 M	50mm crack in bottom at chime
	3.6 M	300mm tear, bottom chime
	3.4 M	75mm tear, at bottom chime
	3.2 M	610mm tear, around bottom chime
	2.8 M	Small crack near chime
	3.2 M	150mm tear, bottom chime
	3.6 M	610mm around bottom chime
	3.4 M	150mm tear, bottom chime
	3.2 M	50mm crack, in chime
	3.2 M	300mm tear, bottom chime
N	Bottom Drop	
	5.2 M	75mm crack, bottom chime
N	Top Drop	
	5.0 M	50mm gap where side seam opened at top chime

TABLE 3

Metal Fractures Observed During Drop Testing

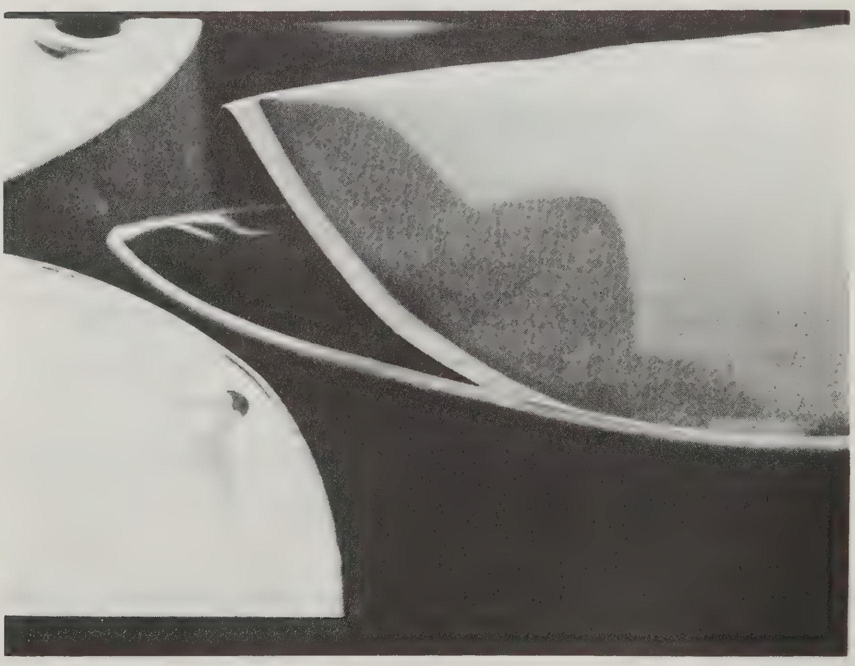
A crack is defined as a metal fracture observed as a thin break line in the metal.

A tear is defined as a metal fracture observed as a major rupture in which the broken edges are separated, leaving wide gaps. (Photographs 3 and 4).



Photograph 3

Typical metal crack at 208L drum chime after drop testing



Photograph 4

Major metal tear of 208L drum after drop testing

4.3 208L, C.T.C. (D.O.T.) 17E, Steel Drums, Hydrostatic Pressure Tests

C.T.C. (D.O.T.) requires that 17E steel drums be able to retain a hydrostatic pressure of 15 psi (103 kPa) for 5 minutes. U.N. recommendations for hydrostatic tests are based on the fill substance vapour pressure, but 100 kPa is referenced as a minimum value.

Hydrostatic test data are summarized in Table 4. A graphic representation of the data is provided on page 29.

	Drum Code						
Replicate No.	C	D	E	F	M	N	O
1	365	228	428	179	359	538	297
2	331	228	407	166	352	414	297
3	324	152	400	166	345	400	283
4	317	428	282	131	365	365	297
5	345	138	269	117	345	372	290
6	331	400	228	124	324	359	290
7	331	379	262	97*	193	379	283
8	317	386	297	207	338	379	290
9	331	372	303	90*	359	393	290
10	317	441	317	124	359	379	283
Mean	331	315	319	140	334	398	290
Standard Deviation	15	116	69	38	51	52	6

*Below minimum C.T.C. (D.O.T.) value

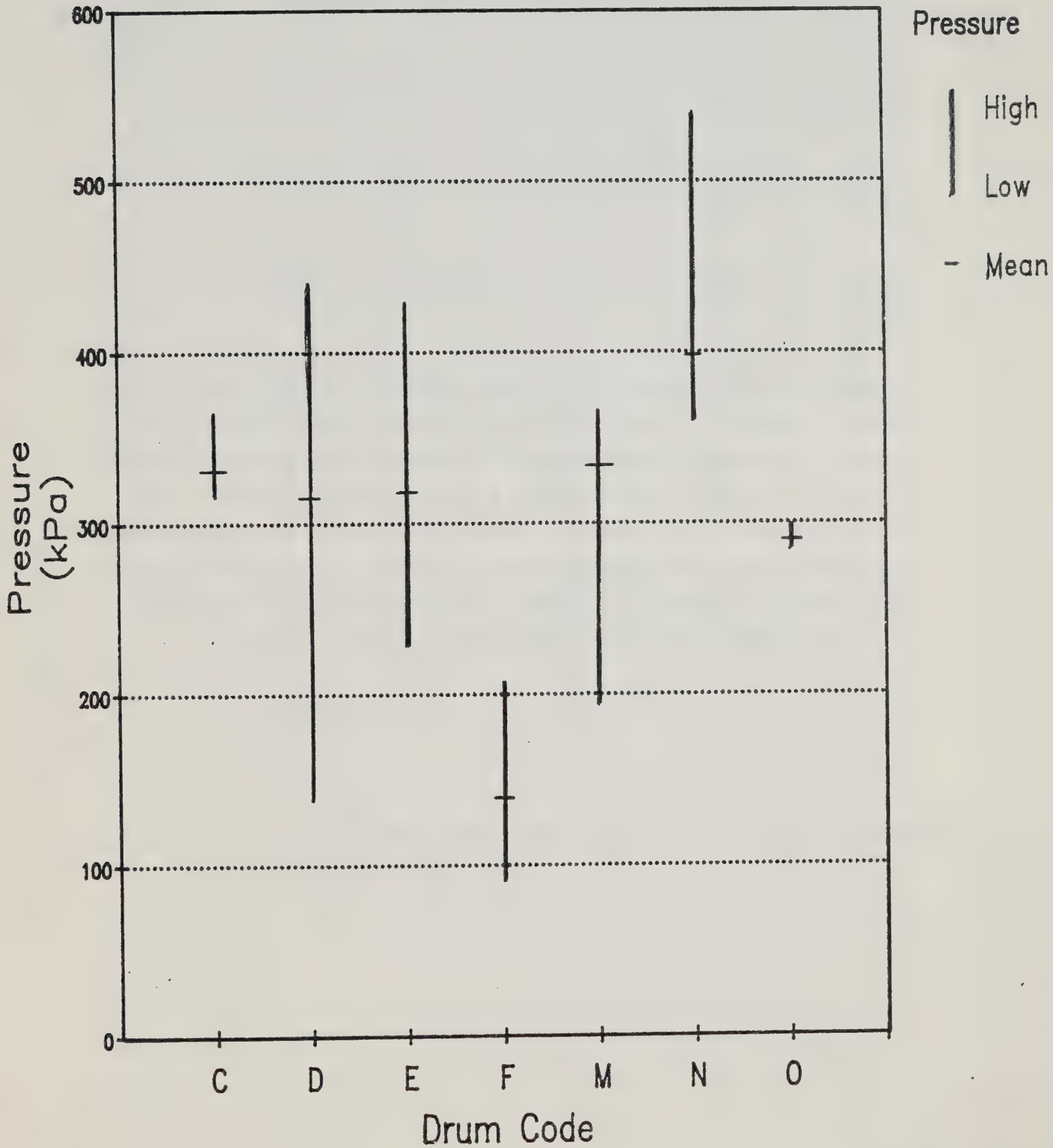
TABLE 4

Hydrostatic Pressure Tests of 208L Steel Drums (kPa)

Photograph 5

Typical 208L drum appearance after hydrostatic testing

HYDROSTATIC PRESSURE TESTS
208 Litre Steel Drums



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4.4 A.S.T.M. D4169 Sequence Test on Drums Level 1

Three replicate sequence tests on each drum type were conducted at assurance level 1. Data are reported in Table 5. (The order of presentation is in approximate order of ranking by drop failure height with "N" having the highest mean failure height and "C" having the lowest.

All failures occurred during simulated rail switching and at the top drum chime.

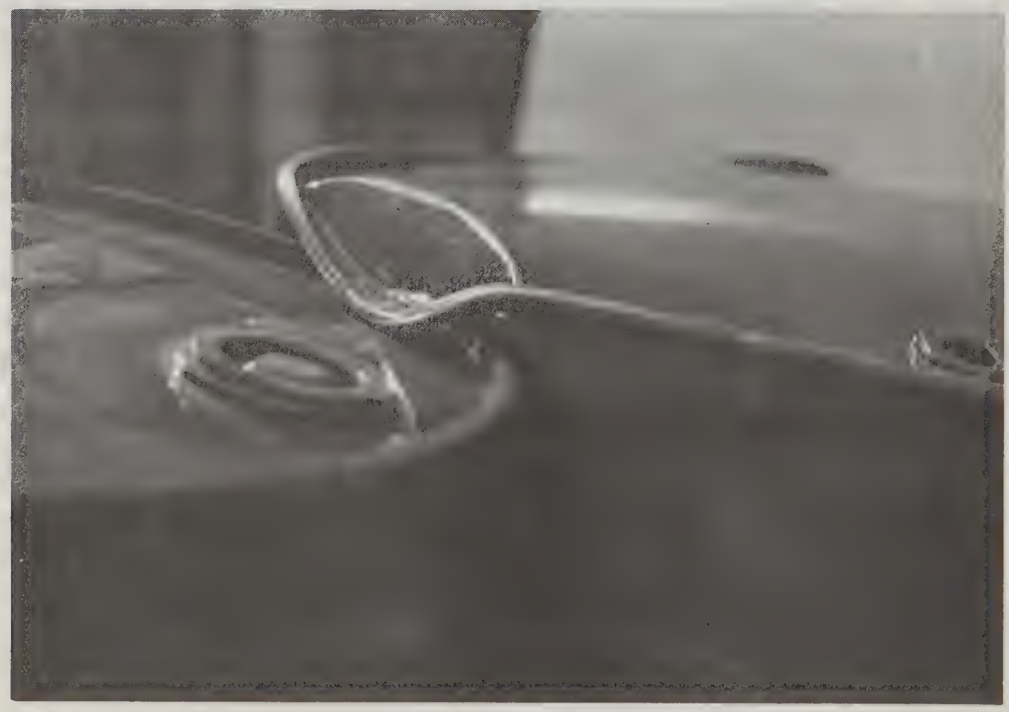
A complete test sequence would have required a final series of tilt drops. However, after conclusion of the rail switching test, at level 1, the drums were so distorted that many of them had trouble remaining upright, and certainly a clear definition of the final tilt drop would have been difficult. The final drops were therefore not conducted. The hazard presented to 208L drums by tilt drops is very low and it could be assumed, with some degree of certainty, that such impacts would not have caused further failures.

Code and Specimen No.	Drop Test	Stack Test	Stacked Vibration	Loose Vibration	Rail Switching
N-1	pass	pass	pass	pass	pass
2	pass	pass	pass	pass	pass
3	pass	pass	pass	pass	pass
D-1	pass	pass	pass	pass	pass
2	pass	pass	pass	pass	fail
3	pass	pass	pass	pass	pass
F-1	pass	pass	pass	pass	pass
2	pass	pass	pass	pass	fail
3	pass	pass	pass	pass	fail
O-1	pass	pass	pass	pass	fail
2	pass	pass	pass	pass	pass
3	pass	pass	pass	pass	pass
M-1	pass	pass	pass	pass	pass
2	pass	pass	pass	pass	pass
3	pass	pass	pass	pass	pass
E-1	pass	pass	pass	pass	pass
2	pass	pass	pass	pass	pass
3	pass	pass	pass	pass	fail
C-1	pass	pass	pass	pass	pass
2	pass	pass	pass	pass	fail
3	pass	pass	pass	pass	pass

TABLE 5

C.T.C. (D.O.T.) 17E, 208L Steel Drums, A.S.T.M. D4169 Test at Level 1

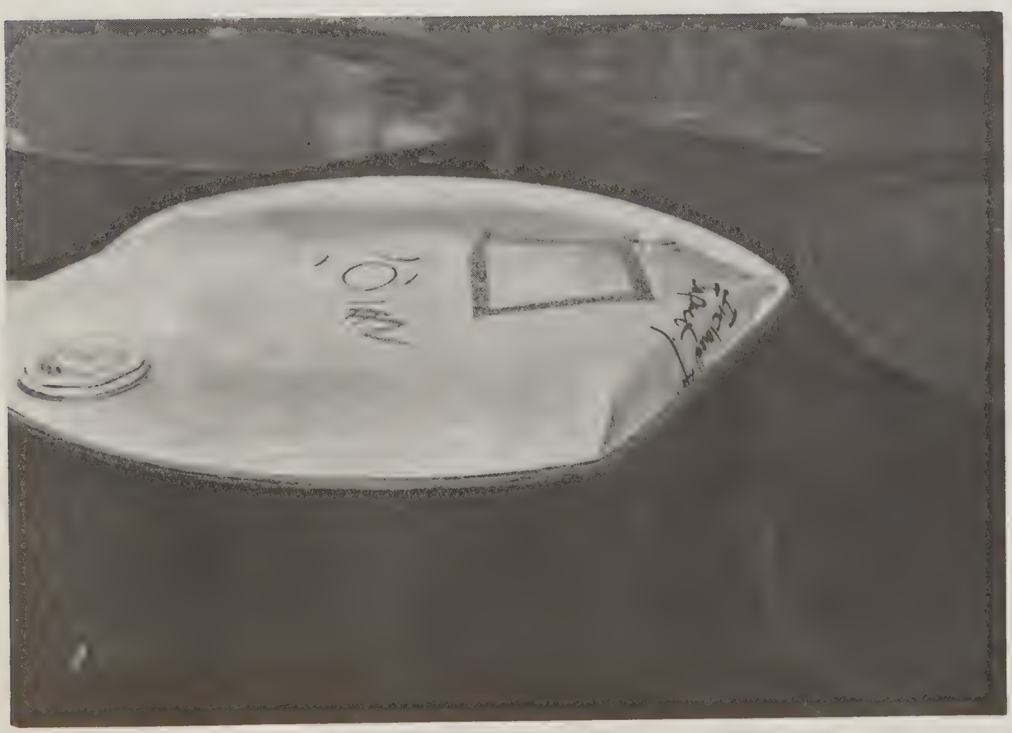
Photograph 6



Photograph 7

Phtographs 6 and 7 - 208L drums after the third impact of an A.S.T.M. D4169, level 1 simulated rail shunting test

Photograph 8



Photograph 9

Photographs 8 and 9 - Leading edges of 208L drums after completion of A.S.T.M. D4169, simulated rail shunting at level 2.

4.5 A.S.T.M. D4169 Sequence Test on Drums, Level 2

Three replicates each of drums D, F, O, E and C were evaluated at level 2. All drum types and replicates successfully passed the test sequence.

4.6 Leak Pressure of Drop Tested Drums

An exploratory investigation into the leakage resistance left in a drum after drop testing was conducted. Briefly, drop tested drums that had passed the drop test, were subjected to a hydrostatic pressure until leakage was observed. The following observations were made:

"C" Drums

Drop Height (m)	Leak Pressure (Kpa)
1.2	20
1.2	30
1.2	50
1.2	70
1.2	80
1.0	80
1.0	80
0.8	80

"E" Drums

Drop Height (m)	Leak Pressure (Kpa)
1.5	40
1.5	60
1.5	70
1.5	80

The prospects for developing a useful co-relation seemed poor and the program was dropped.

5. PERFORMANCE EVALUATIONS OF 20L, PLASTIC PAILS

5.1 Drop Test Results

C.G.S.B. 43-GP-60M, (TC 35) provides for a molded polyethylene container not exceeding 28L capacity and having a removeable head. The standard requires testing with a dry powder fill. Notwithstanding the test methodology, many of these pails are used with liquid fills. Further, U.N. recommendations require that containers for liquids be tested with liquid fills of similar density and viscosity to the substance being packaged. The test procedure was conducted using a water fill to examine the performance of the pails under these conditions. (The containers evaluated did not claim to meet these requirements but were felt to be "state-of-the-art" and representative of possible candidates for classification).

U.N. recommendations for drop tests are as follows:

	Drop Height
Packing group 1	1.8m
Packing group 2	1.2m
Packing group 3	0.8m

Drop test data are summarized in Table 6. Graphic representations of the total drops for each pail type and orientation are given on pages 37 and 38.

Code	Orientation	Total Dropped	Total Failed	Failing Drop Height Calculated Mean	Failing Drop Height Calculated Standard Deviation
J	Top	50	26	0.9	0.1
	Bottom	53	24	2.4	0.4
K	Top	50	27	0.7	0.1
	Bottom	52	22	2.9	0.3

TABLE 6
Drop Test Data - T.C. 35 Plastic Pails

5.2 20L, Plastic Pails, Drop Test Observations

Code "J" 20L Plastic Pail

These containers failed in several different manners. The majority of top and bottom failures were observed as leaks past the lid seal. Three containers were punctured by the ends of the wire handle being pushed through the pail. Ten top drop failures were caused by partial separation of the lid from the pail.

The containers originally submitted would not seal properly when the lids were fitted. The containers tested were a second submission.

Code "K" 20L Plastic Pail

The failures for both top and bottom drops were observed as lid separation from the pail. Failures ranged from drops of water to complete lid removal.

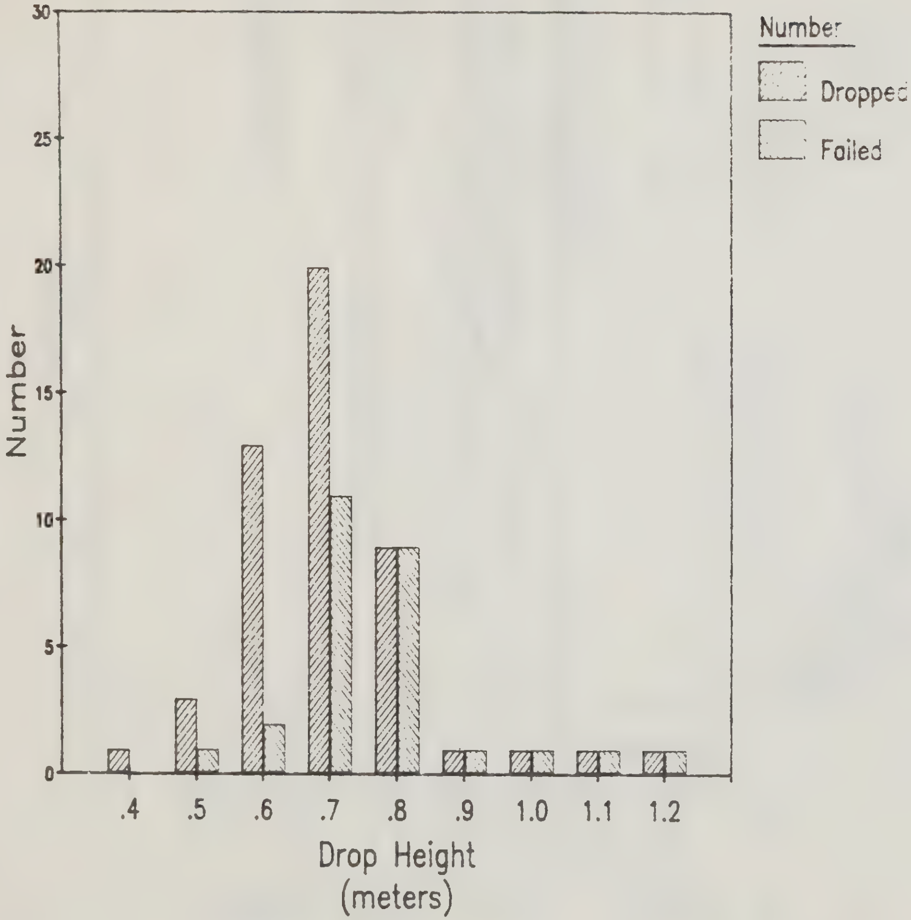
These containers were also the second submission. The first set of containers would not seal when the lid was applied.

DROP TEST DATA, CODE: K

20L T.C. 35 Plastic Pail

Orientation: Top Mean: 0.65m SD: 0.12m

No. Tested: 50 No. Failed: 27

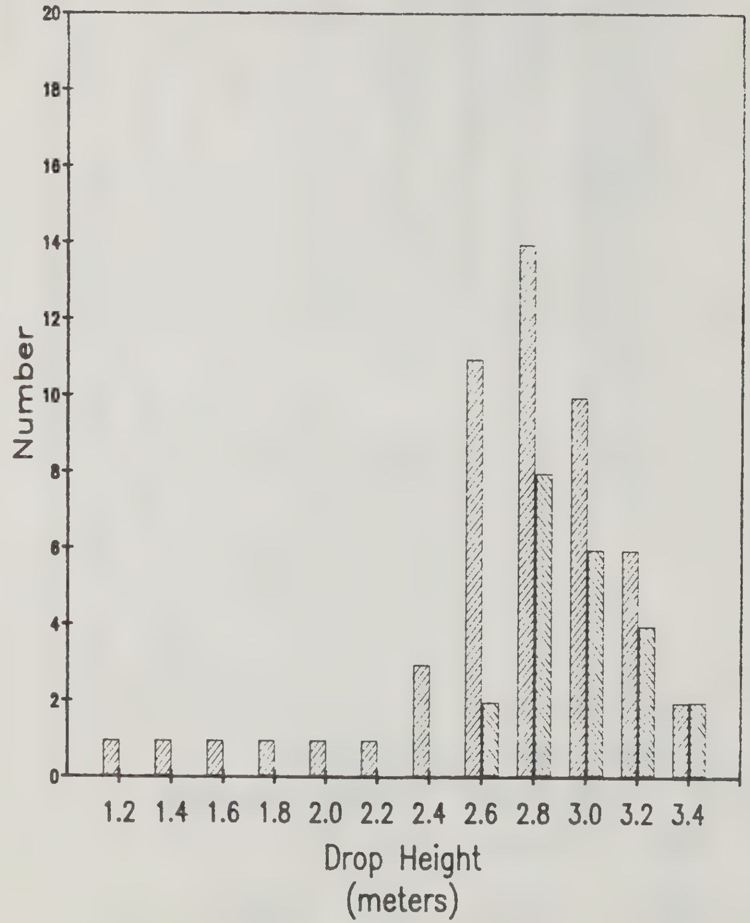


DROP TEST DATA, CODE: K

20L T.C. 35 Plastic Pail

Orientation: Bottom Mean: 2.90m SD: 0.31m

No. Tested: 52 No. Failed: 22



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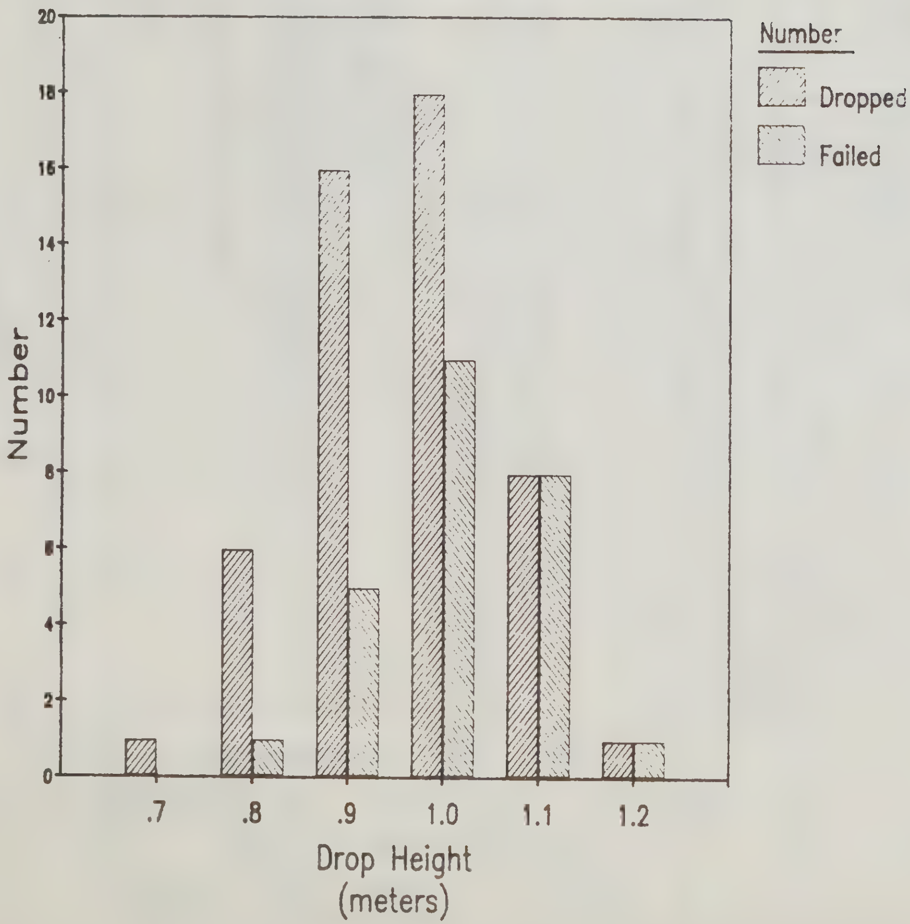
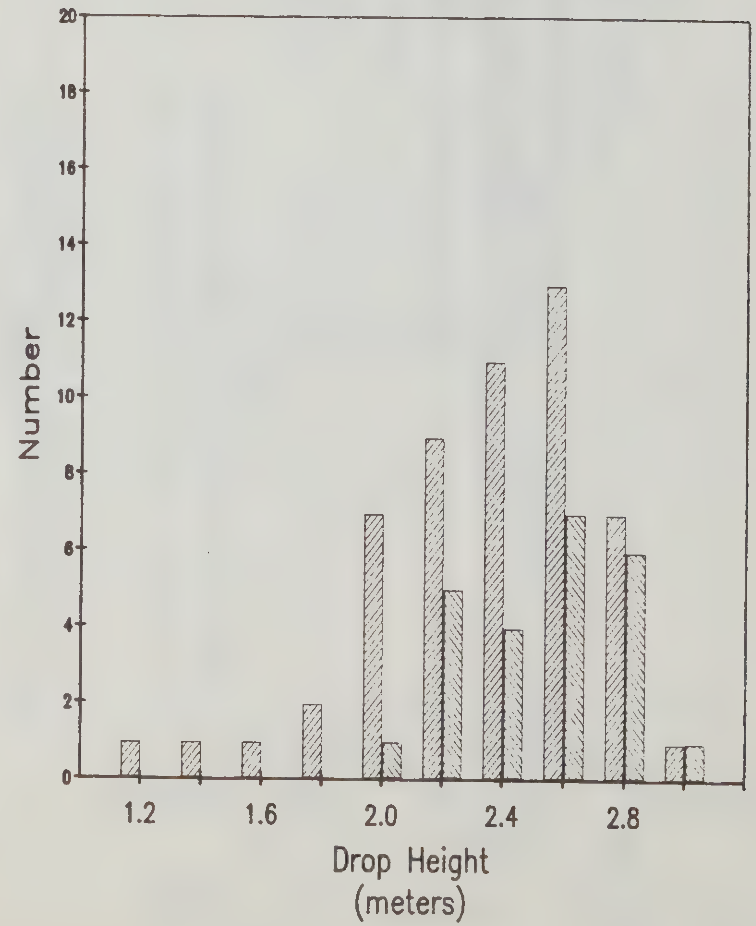
DROP TEST DATA, CODE: J
20L T.C. 35 Plastic Pail
Orientation: Top Mean: 0.94m SD: 0.11m
No. Tested: 50 No. Failed: 26



DROP TEST DATA, CODE: J
20L T.C. 35 Plastic Pail
Orientation: Bottom Mean: 2.41m SD: 0.37m
No. Tested: 53 No. Failed: 24



6. PERFORMANCE EVALUATIONS OF 20L STEEL PAILS

6.1 Drop Test Data

Specifications (e.g. .C.T.C./D.O.T.) for open head pails usually require testing with a dry powder fill. Notwithstanding the test methodology, many of these pails are used to ship liquids. Further, U.N. recommendations require that containers be tested with liquid fills of similar density and viscosity to the substance being packaged. This test program was conducted with a water fill to examine the performance of the pails under these conditions.

Steel pails are required to be able to pass drop tests from the following heights:

To meet C.T.C. (D.O.T.)	To meet U.N. Recommendations
17E - 1.2m (liquid fill)	Packing group I - 1.8m
37A - 1.2m (dry fill)	Packing group II - 1.2m
37B - 1.2m (dry fill)	Packing group III - 0.8m
37C - 1.2m (dry fill)	

Drop test data are summarized in Table 7. Graphic representatives of the total drops for each pail type and orientation are given on pages 41 through 44.

Code	Type	Orientation	Total Dropped	Total Failed	Failing Drop Height Calculated Mean	Failing Drop Height Calculated Std. Dev.
I	17E	Top	50	24	1.7m	0.2m
		Bottom	50	24	1.9m	0.5m
L	37A	Top	50	27	0.8m	0.2m
		Bottom	50	25	0.9m	0.3m
G	37B	Top	50	23	1.8m	0.4m
		Bottom	60	31	2.3m	0.7m
H	37C	Top	50	25	0.9m	0.2m
		Bottom	50	27	0.9m	0.6m

TABLE 7

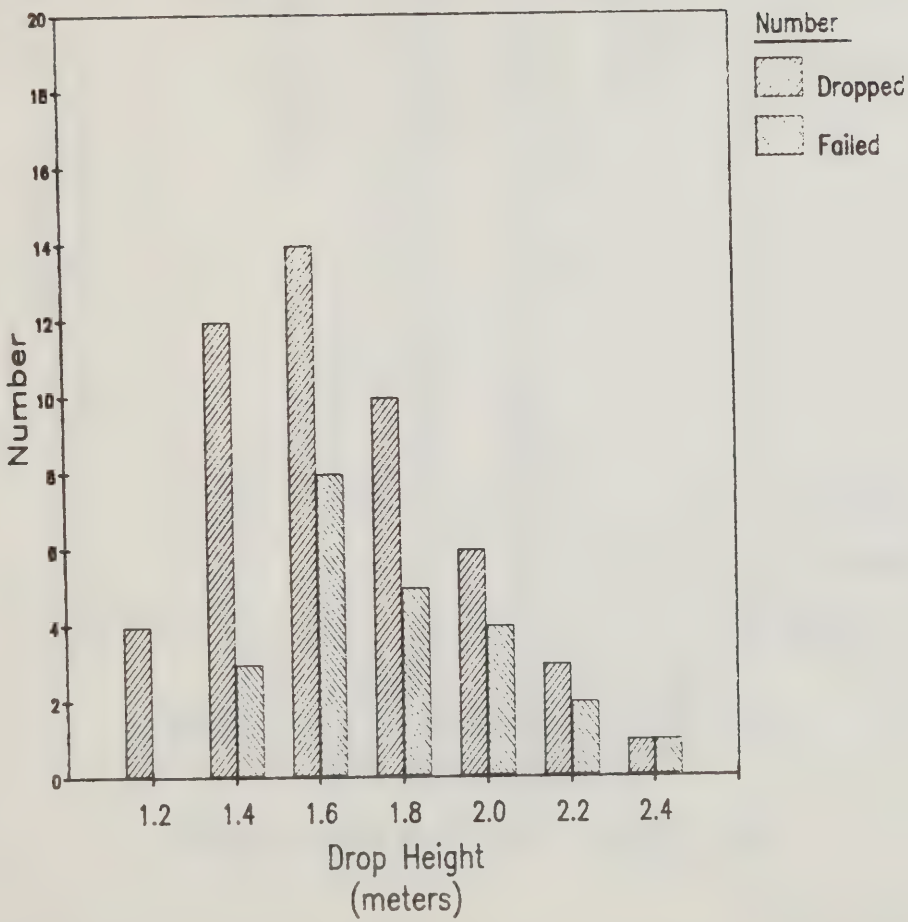
Drop Test Data - 20L Steel Pails

DROP TEST DATA, CODE: G

20L 37B Steel Pail

Orientation: Top Mean: 1.77m SD: 0.41m

No. Tested: 50 No. Failed: 23

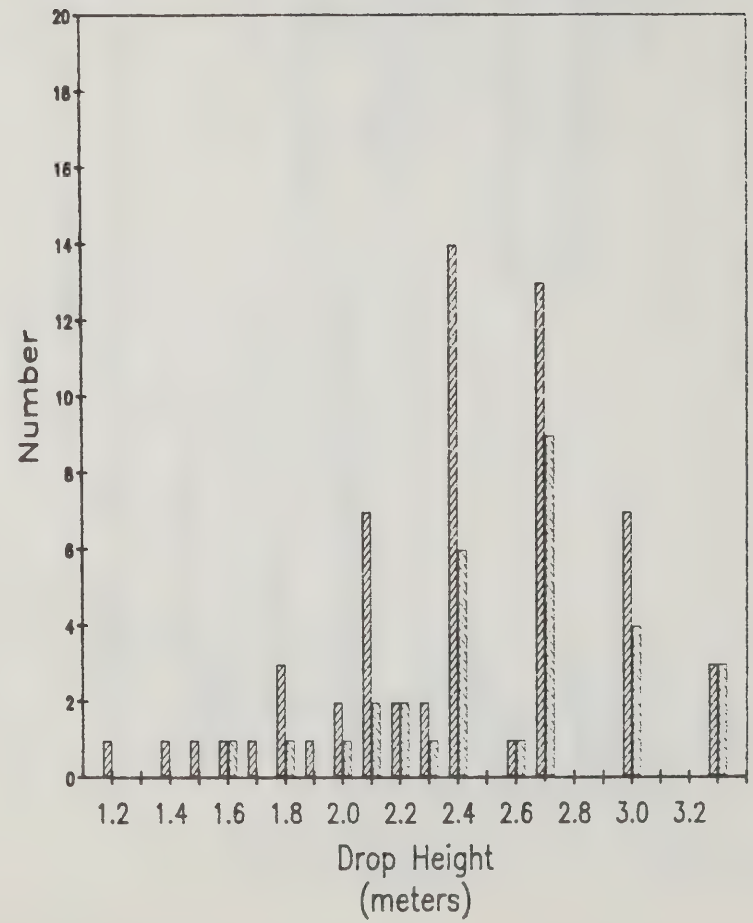


DROP TEST DATA, CODE: G

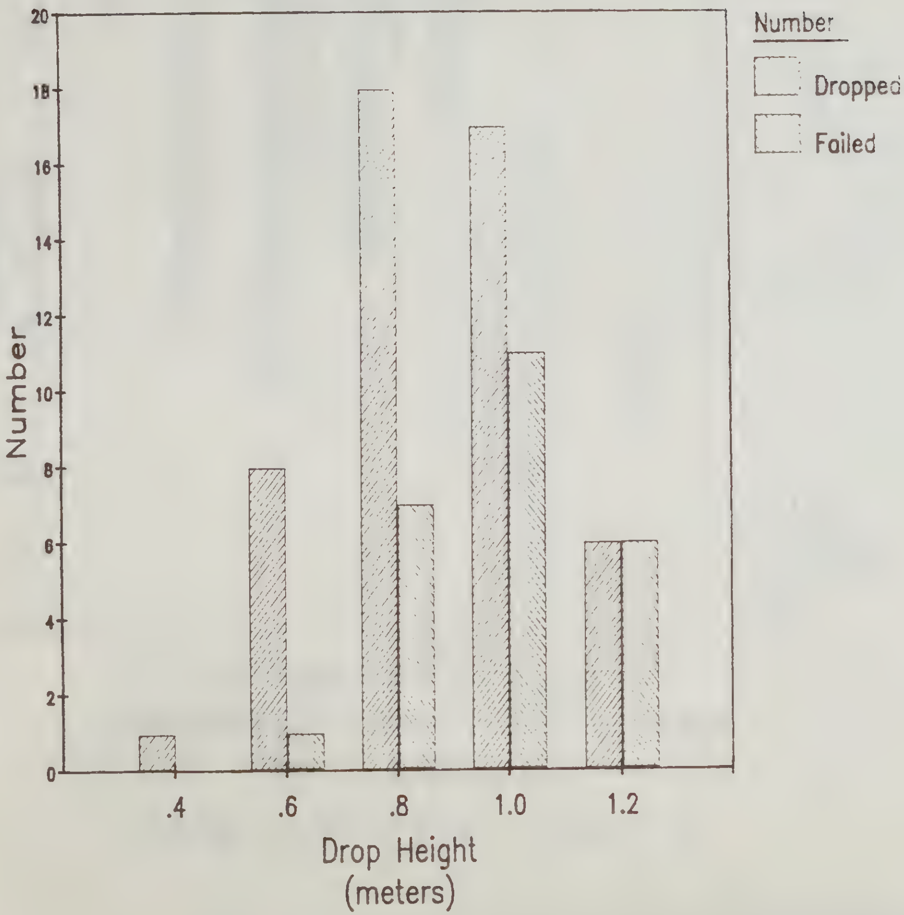
20L 37B Steel Pail

Orientation: Bottom Mean: 2.26m SD: 0.70m

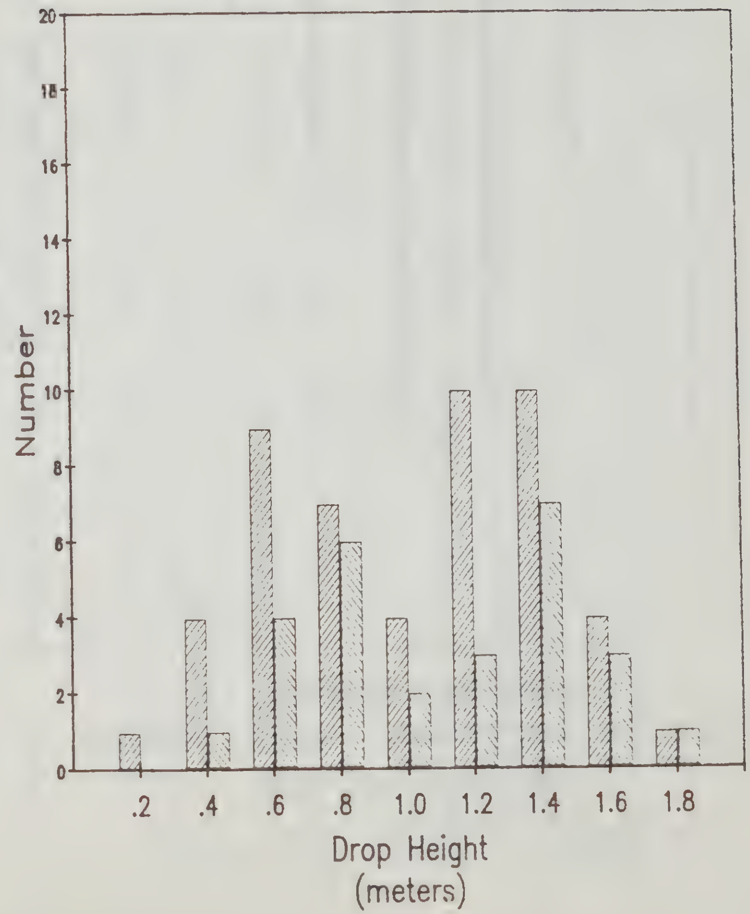
No. Tested: 60 No. Failed: 31



DROP TEST DATA, CODE: H
20L 37C Steel Pail
Orientation: Top Mean: 0.87m SD: 0.20m
No. Tested: 50 No. Failed: 25



DROP TEST DATA, CODE: H
20L 37C Steel Pail
Orientation: Bottom Mean: 0.94m SD: 0.61m
No. Tested: 50 No. Failed: 27

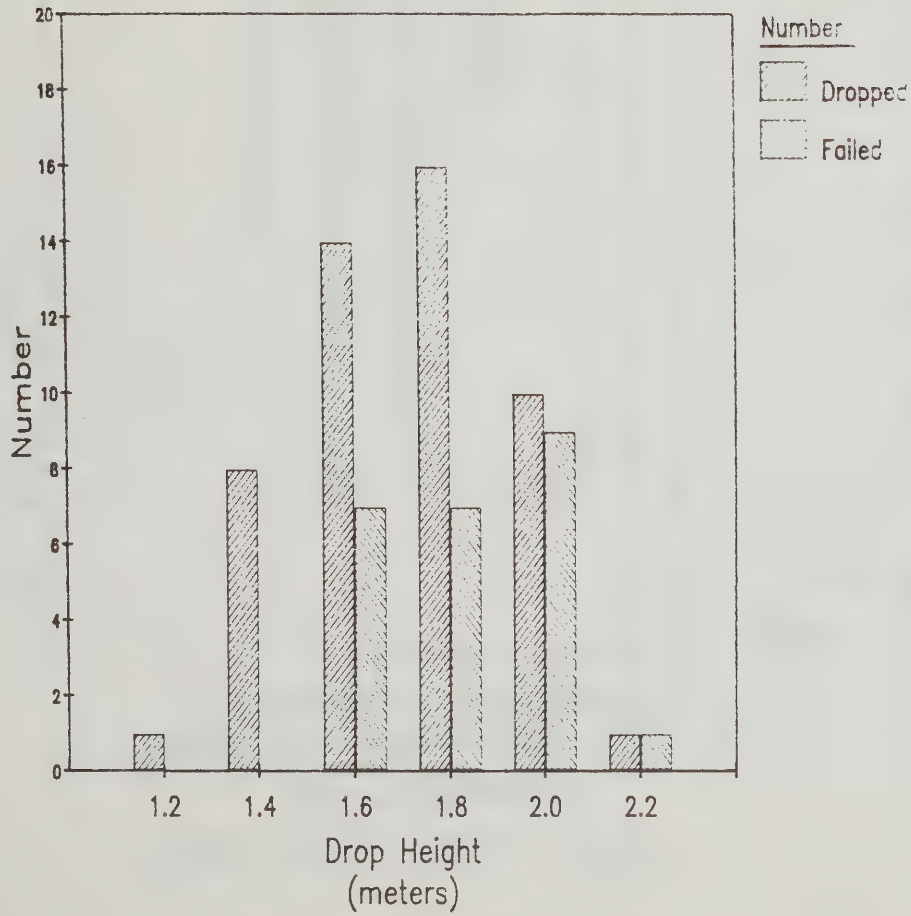


DROP TEST DATA, CODE: I

20L 17E Steel Pail

Orientation: Top Mean: 1.73m SD: 0.22m

No. Tested: 50 No. Failed: 24

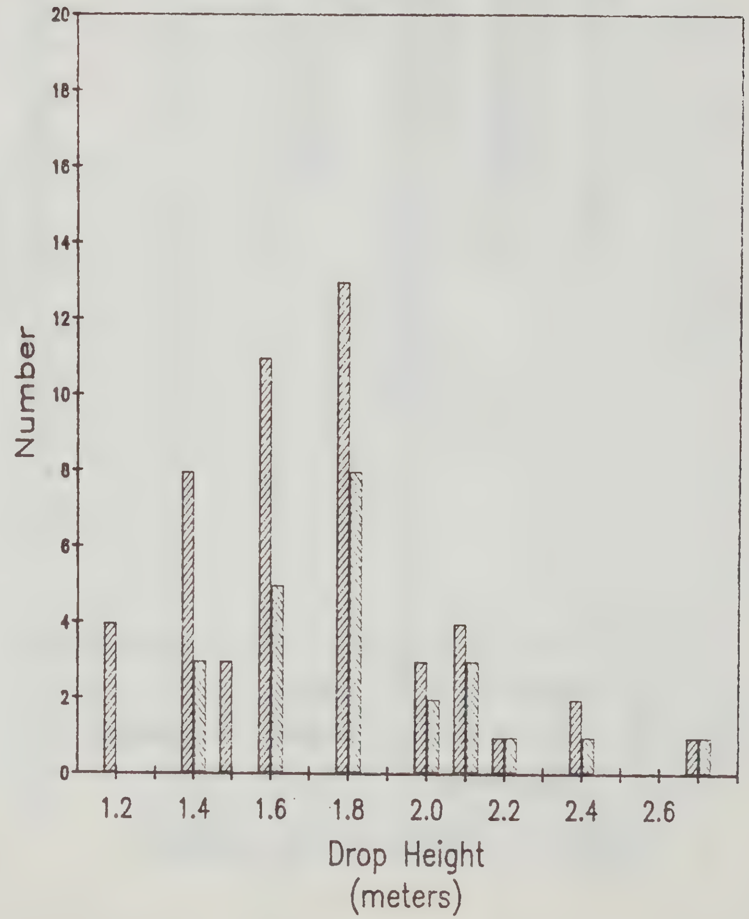


DROP TEST DATA, CODE: I

20L 17E Steel Pail

Orientation: Bottom Mean: 1.85m SD: 0.51m

No. Tested: 50 No. Failed: 24



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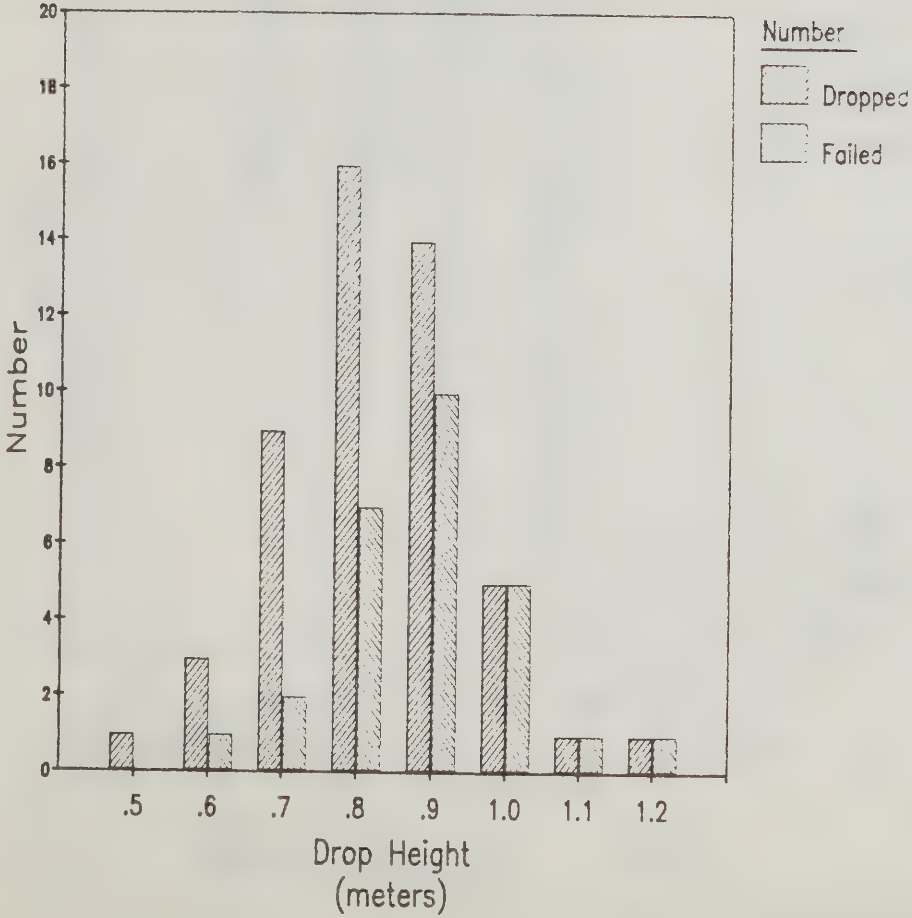
DROP TEST DATA, CODE: L

20L 37A Steel Pail

Orientation: Top Mean: 0.78m SD: 0.16m

No. Tested: 50 No. Failed: 27

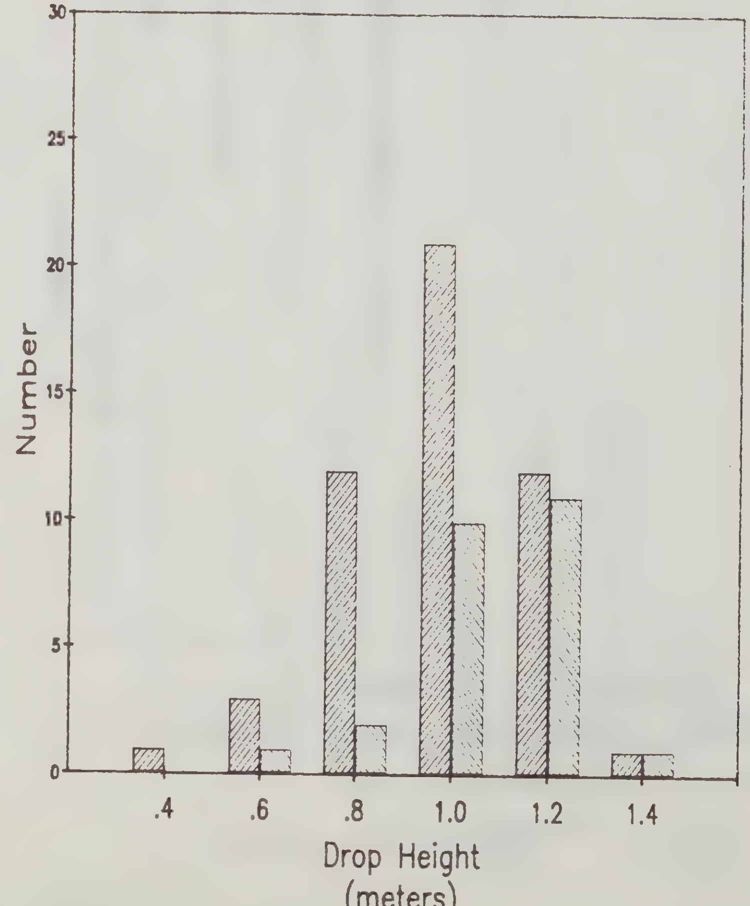


DROP TEST DATA, CODE: L

20L 37A Steel Pail

Orientation: Bottom Mean: 0.92m SD: 0.27m

No. Tested: 50 No. Failed: 25



6.2 Miscellaneous Observations

Code "I" 20L, C.T.C. (D.O.T.) 17E

The failed containers for both bottom and top drops all leaked at the impacted chime.

Code "L" 20L, C.T.C. (D.O.T.) 37A

The failed containers for both bottom and top drops all leaked at the lid seal.

Code "G" 20L, C.T.C. (D.O.T.) 37B

All top and bottom drop failures were observed as leaks from the impacted chime.

Code "H" 20L, C.T.C. (D.O.T.) 37C

Top and bottom failures were all observed to leak from the lid seal. Some of the containers which were judged to have passed, sprayed out small quantities of water on impact.

Pail metal thickness was verified (Table 8). Nominal and minimum metal thickness is given below for typical pail gauges.

Gauge No.	Nominal	Minimum
24	0.0239" (0.607mm)	0.0209" (0.531mm)
26	0.0179" (0.455mm)	0.0159" (0.404mm)
28	0.149" (0.378mm)	0.0129" (0.328mm)

Code and Replicate		Pail Type	Gauge Marked on Pail	Measured Thickness (inches) Top	Body	Bottom
I	1	17E	24	.0246	.0235	.0233
	2	17E	24	.0245	.0236	.0234
	3	17E	24	.0237	.0244	.0231
G	1	37B	26	.0192	.0187	.0191
	2	37B	26	.0197	.0198	.0191
	3	37B	26	.0191	.0185	.0191
L	1	37A	26	.0188	.0193	.0193
	2	37A	26	.0195	.0201	.0186
	3	37A	26	.0192	.0194	.0189
H	1	37C	28/26	.0192	.0180	.0170
	2	37C	28/26	.0192	.0180	.0170
	3	37C	28/26	.0191	.0178	.0165

Table 8

Metal Gauge of Pails

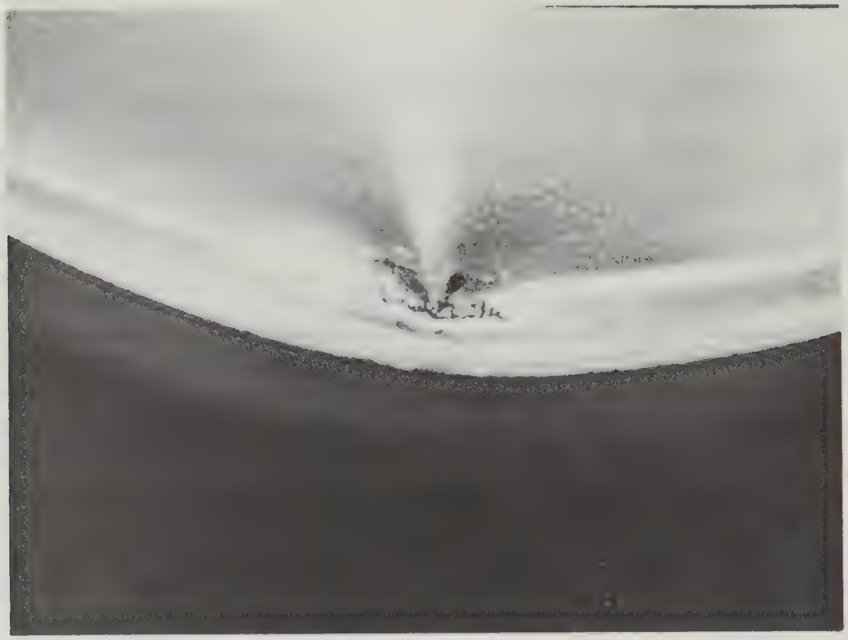
6.3 A.S.T.M. D4169, Performance Testing

Pail types 17E and 37B (closed heads) were subjected to A.S.T.M. performance testing at all three assurance levels. The data is summarized in Table 9.

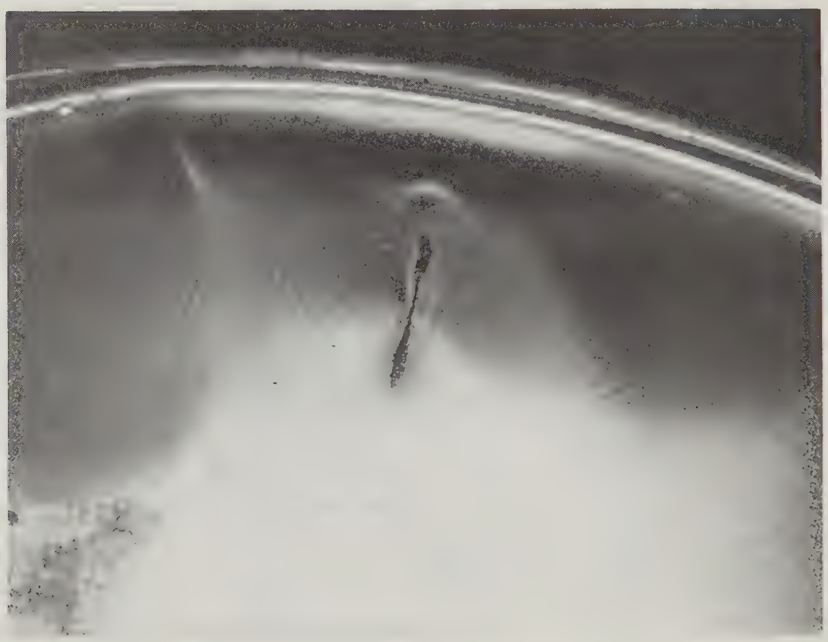
Code and Replicate	Pail Type	Drop Test	Stack Test	Stacked Vibration	Loose Vibration	Rail Switching	Drop Test
Level 1 Test Sequence							
I-1	17E	pass	pass	pass	fail	-	-
I-2	17E	pass	pass	pass	fail	-	-
I-3	17E	pass	pass	pass	fail	-	-
G-1	37B	pass	pass	fail	-	-	-
G-2	37B	pass	pass	pass	fail	-	-
G-3	37B	pass	pass	fail	-	-	-
Level 2 Test Sequence							
I-1	17E	pass	pass	pass	fail	-	-
I-2	17E	pass	pass	pass	fail	-	-
I-3	17E	pass	pass	fail	-	-	-
G-1	37B	pass	pass	fail	-	-	-
G-2	37B	pass	pass	fail	-	-	-
G-3	37B	pass	pass	fail	-	-	-
Level 3 Test Sequence							
I-1							
I-2	Pass all tests						
I-3							
G-1							
G-2	Pass all tests						
G-3							

TABLE 9

A.S.T.M. D4169 Performance Testing of 20L Steel Pails



Photograph 10



Photograph 11

Photographs 10 and 11 - Typical failures on 20L pail bottom after level 1, A.S.T.M. vibration elements

7. DROP TEST PERFORMANCE EVALUATION OF 208L PLASTIC DRUMS

The manufacturer's code of the drum is "B".

All drops were conducted at ambient conditions.

Some difficulty was experienced in getting an adequate seal on the bung caps. Approximately half of the drums leaked past the bung after being torqued with the appropriate tool. Since the leakage observed was very small, drop tests were continued and any small leakages past the bung were discounted for the purposes of this program.

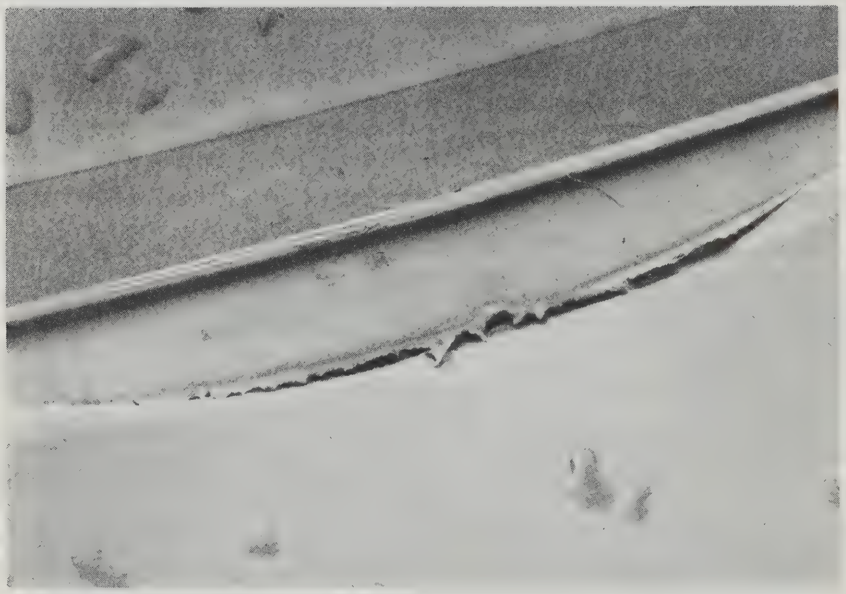
During drop testing, a positive pressure would be observed when a bung was removed. It was further observed that when the drum was dropped with the mold part line perpendicular to the floor, the container would fail at much lower drop heights. Bottom drops from drop 24 to 50 and all top drops were conducted in this orientation.

Failures tended to be parallel to the mold part line but not directly on the line (see Photograph 12). On four top drop failures, cracks around the chime were also observed in conjunction with cracks along the part line.

Drop test data are summarized in Table 10 and graphically illustrated on page 52.

Plastic drums are required to be able to pass drop tests from the following heights:

To meet C.T.C. (D.O.T.)	To meet U.N. Recommendations
1.2m	Packing Group I - 1.8m
	Packing Group II - 1.2m
	Packing Group III - 0.8m



Photograph 12

Typical failure across bottom of a 208L
plastic drum after drop testing

Drop Orientation	Total Dropped	Total Failed	Mean	Std. Dev.
bottom (mold line perpendicular)	27	19	1.90	0.56
bottom (mold line random)	23	6	3.85	0.53
combined bottom drops	50	25	2.87	1.25
Top	50	19	3.9m	0.64m

TABLE 10

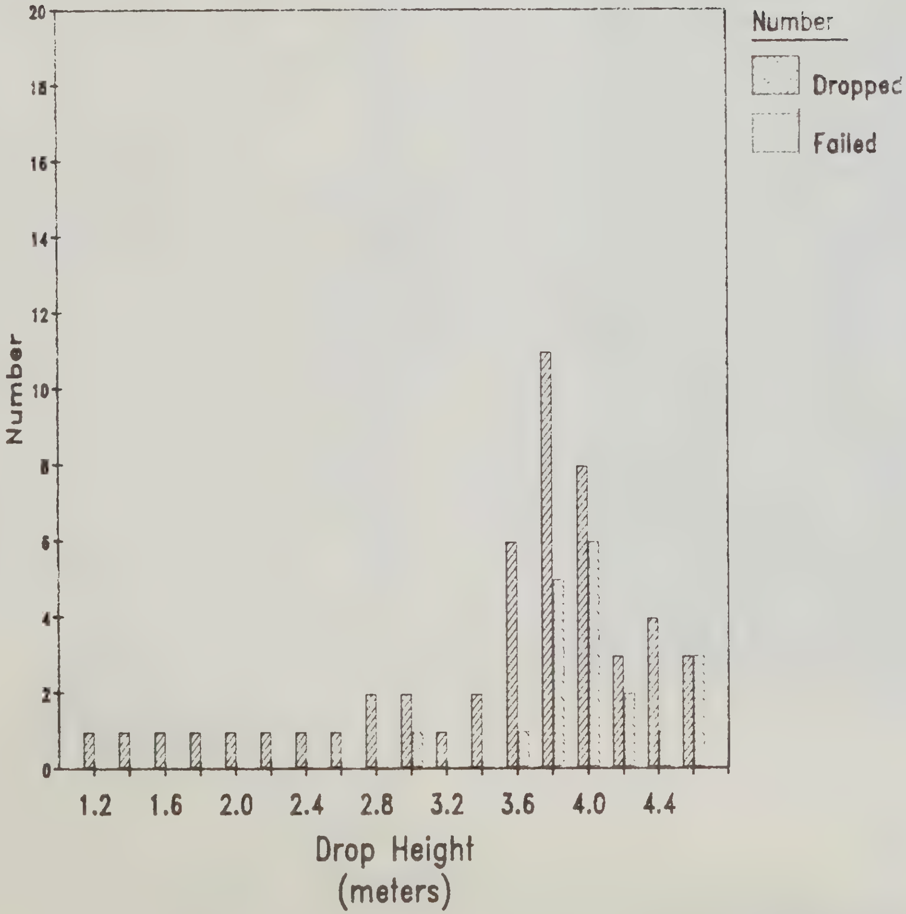
Drop Test Summary of 208L Plastic Drums

DROP TEST DATA, CODE: B

208L Polyethylene Drum

Orientation: Top   Mean: 3.94m   SD: 0.64m

No. Tested: 50   No. Failed: 19

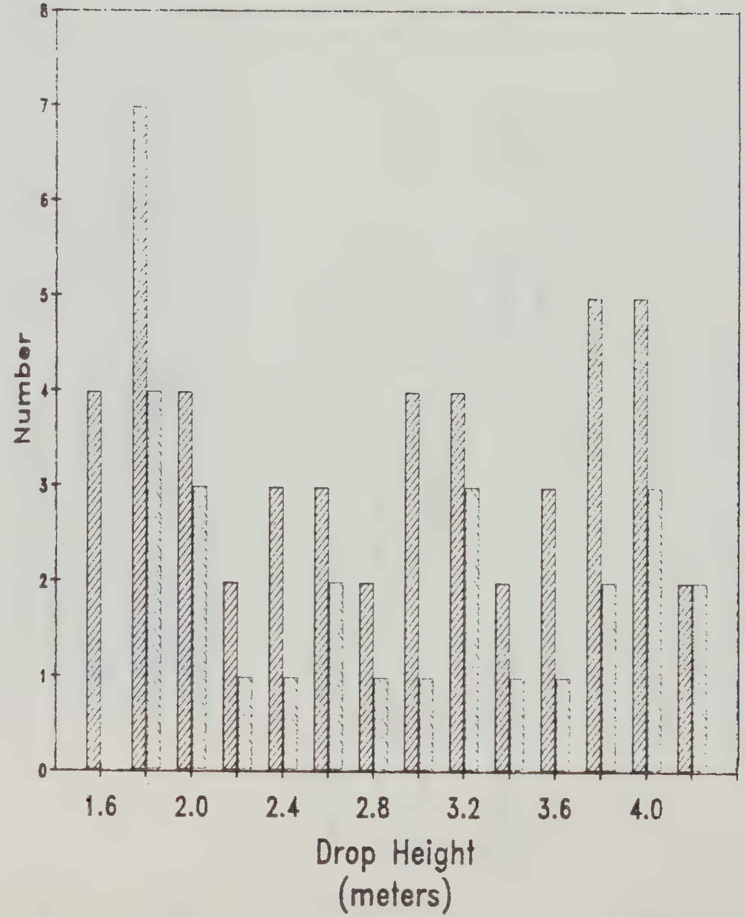


DROP TEST DATA, CODE: B

208L Polyethylene Drum

Orientation: Bottom   Mean: 2.87m   SD: 1.25m

No. Tested: 50   No. Failed: 25



8. PERFORMANCE EVALUATION OF CORRUGATE CONTAINER SYSTEM

A corrugate container (FEFCO code 0204) with a partition and holding twelve 1 litre bottles of a sulphuric acid based cleaning solution, was drop tested in accordance with recommended regulatory practice. The doublewall corrugate construction was identified as follows on the boxmakers certificate:

Burst test	- 275
Weight of Facings	- 110
Code	- C16

The container was nominally 362mm x 270mm x 298mm, and when filled as for shipment, had a gross mass of 13 kg. No claim for compliance with regulations was stamped on the box.

The drop tests were conducted at ambient and at $-18^{\circ}C$ from 1.8m, in accordance with U.N. recommendations for a packing group I substance. Although no claim was made for C.T.C. (D.O.T.) compliance, drop test procedures for a 12A box are provided below for comparison purposes:

Orientation	Height
Flat bottom	1.2m
Flat side	1.2m
Flat end	1.2m
Flat top	0.6m

Both U.N. and C.T.C. procedures do not require any box to be dropped more than once.

Orientation	Ambient (4 replicates)	-18 C (5 replicates)
Flat Bottom	all pass	all pass
Flat Top	all pass	all pass
Short Side	all pass	one bottle leaked[1]
Long Side	all pass	all pass
On Corner	all pass	one bottle leaked[2]

TABLE 11

Corrugate Container Drop Tests, One Drop Per Container

[1] small crack at part line along base

[2] pinhole leak at bottle crease mark

In order to develop better indication of the sytem's performance characteristics, the ambient and cold drop tests were repeated, excepting each container was subject to all five drops, in sequence (Table 12).

Orientation	Ambient (10 replicates)	-18 C (10 replicates)
Flat Bottom	all pass	all pass
Flat Top	all pass	all pass
Short side	all pass	all pass
Long side	all pass	all pass
Diagonal on short edge	all pass	all pass

TABLE 12

Drop Tests, Sequential

9. DISCUSSION

9.1 Drum Drop Tests and Dangerous Goods Code Requirements

Assuming that the drum drop test failures follow a standard distribution curve, the probable pass rate for any drop height can be calculated using:

$$z = \frac{X-m}{6}$$

where z = distance from the population mean in units of the standard deviation

X = any population value

m = mean

6 = standard deviation

The value z is entered into a cumulative normal distribution table to obtain a percent estimate for passing a drop test at the three packing group levels (1.8m, 1.2m and 0.8m) described in U.N. recommendations (Table 13).

Drum Code	Drop Orientation	Failing Drop Height (m) Mean	Std. Dev.	Probability of passing 1.8m	1.2m	0.8m
C	Bottom	1.09	0.36	2%	38%	70%
	Top	0.83	0.40	1%	18%	53%
D	Bottom	4.47	1.17	99%	100%	100%
	Top	2.13	0.77	67%	89%	96%
E	Bottom	1.93	0.55	60%	91%	98%
	Top	1.12	0.55	11%	44%	72%
F	Bottom	2.95	0.84	91%	98%	100%
	Top	1.03	0.32	1%	30%	76%
M	Bottom	1.33	0.33	8%	65%	95%
	Top	1.62	0.61	38%	76%	90%
N	Bottom	4.33	1.22	98%	100%	100%
	Top	4.47	0.78	100%	100%	100%
O	Bottom	1.65	0.31	32%	93%	100%
	Top	1.45	0.41	19%	73%	95%

TABLE 13

Calculated Percent 208L Steel Drums
Able to Pass Regulatory DropTests
(rounded to the nearest %)

It is clear, from the above, that the majority of drum types tested cannot statistically achieve a 100% pass rate for a 1.2m drop, as described by dangerous goods code requirements for a U.N. packing group 2 material or for a C.T.C. (D.O.T.) regulated drum. Using the strictest interpretation, only drum "N" is able to meet regulatory codes, at this level.

It is disturbing that even if a 95% pass rate were deemed acceptable, four drum types could not meet the requirements for a U.N. packaging group 3 (lowest hazard) material.

It should be noted that all drums tested are commonly used for shipping in North America. It is the impression of the authors, after discussions with various users and warehousers, that the problems are minimal. (See also Transport Canada Observations, Appendix 6). This is not to suggest that regulatory requirements are too severe or that the typical North American drum construction is adequate. However, determination of "pass" criteria should be carefully examined. In particular, it is suggested that a strict pass/fail height may not be appropriate and that the statistical reality of events should be recognized.

Using the data developed as an example, it would appear that in order to be 100% certain of a 1.2m drop test requirement, the mean drop test failure height must be about 4m. In the standard practice used by industry, drums are dropped periodically from 1.2m. Typically the numbers tested have poor statistical validity, and a "pass" at 1.2m does not tell us much about the drum or the population.

During the course of informal discussion, ORF has learned that at least one drum manufacturer is using a staircase method similar to that developed in this program. Such a procedure has much to

recommend it as a quality control tool. It provides calculated numerical values that can be used to monitor and improve drum quality, as well as to ensure, in a statistically valid manner, that production will meet regulatory requirements.

9.2 Co-relation of Average Drum Drop Test Height and A.S.T.M. D4169

Proposing that a drum's overall strength can be represented by the average of top and bottom mean drop heights to failure, we can arrange the tested drums in order of their "apparent resistance to damage". This ranking can then be compared to the ability of the drums to withstand A.S.T.M. D4169 performance tests.

Drum Code	Type	Average of Top and Bottom Mean Drop Height (m)	Results of 3 Replicate A.S.T.M. D4169 Tests
N	Triple	4.4m	3 pass
D	Triple	3.3m	2 pass
F	Triple	2.0m	1 pass
O	Triple	1.6m	2 pass
E	Double	1.5m	2 pass
M	Double	1.5m	3 pass
C	Double	1.0m	2 pass

TABLE 14

Average Drop Test Height vs A.S.T.M. D4169 at Level 1

Table 14 shows that while the average drop height to failure covers a broad range, the A.S.T.M. test did not provide a clear similar discrimination. This data confirms that the two methods evaluate entirely different characteristics and that A.S.T.M. D4169 cannot be used to judge a container's resistance to catastrophic shock. Since the actual field performance of these drums is unknown, no judgement can be made as to whether drop testing or A.S.T.M. D4169 is the better reflection of real performance.

9.3 Use of D4169 for Drum Performance Tests

An important issue is the inability of drums commonly used, and with apparently reasonable shipping history, to pass a level 1, industry shipping test, as described in A.S.T.M. D4169.

The particular problem is simulated rail switching test which, at level 1, appeared extraordinarily severe. In several instances, the test and backup drum were locked together at the end of the test and had to be removed from the retaining fixtures as a single unit.

"The Railroad Environment" (Technical Research Department, New York Central Railroad Co.) provides this data based on 10,000 measurements per year over 2 years, system wide:

Impact Speed	Percent of Total Number of Impacts
at or below 5 mph	70 %
at 6 mph	17.4%
at 7 mph	6.0%
at 8 mph	3.1%
at 9 mph	2.3%
at 10 mph	1.2%

and that in 3 switching yards, the probability of an impact occuring is:

up to 5 mph	34.5%
over 5 mph	65.5%
over 6 mph	33.2%
over 7 mph	18.5%
over 8 mph	10.2%
over 9 mph	3.6%

TABLE 15

Rail Shunting Speeds

Assuming that 3 shunts represents a typical journey, the probability that two of these three shunts will equal or exceed 8 mph is 0.012.

In choosing to have two impacts at 8 mph and one at 6 mph for level 1 packaging, A.S.T.M. has chosen to work to events having a low probability of occuring. Even the level 2 A.S.T.M. rail shunting sequence is not a highly probable combination of events.

9.4 Co-relation of Least Drop Test Height and Drum Hydrostatic Pressure

Since the majority of drop tested drums failed by leakage past the chime, and since drum hydrostatic failures are also failures at the chime, a comparison of drop height and hydrostatic pressures to failure was made.

For this comparison, the weaker chime of top and bottom as indicated by the mean drop height, was compared to the hydrostatic failure value.

Drum Code	Type	Least Mean Drop Height (m)	Mean Hydrostatic (kPa)
N	Triple Seam	4.33 (bottom)	398
D	Triple Seam	2.13 (top)	315
O	Triple Seam	1.45 (top)	290
M	Double Seam	1.33 (bottom)	334
E	Double Seam	1.12 (top)	319
F	Triple Seam	1.03 (top)	140
C	Double Seam	0.83 (top)	331

TABLE 16

Drop Height vs. Hydrostatic for 208L Steel Drums

The co-relation between the two values was not judged to be significant or useful.

9.5 Drum Metal Gauges

Drum Type	Average Measured Thickness (inches) Top	Side	Bottom	Rankings Drop Test	A.S.T.M. D4169	Hydrostatic Failure
C	.0464	.0344	.0467	7	2 fail	3
D	.0464	.0337	.0472	2	2 fail	5
E	.0468	.0345	.0469	6	2 fail	4
F	.0467	.0345	.0466	3	3 fail	7
M	.0451	.0372	.0457	5	pass	2
N	.0454	.0336	.0472	1	pass	1
O	.0420*	.0349	.0431*	4	2 fail	6
minimum thickness required	.0438(18g)	.0324(20g)	.0438(18g)			
nominal thickness	.0478	.0359	.0478			

TABLE 17

Drum Gauge and Performance Level

*below specification

Most drum metal thicknesses were below the nominal thickness but above the minimum allowed for the specified gauge. Drum type "O" was the single significant exception, with gauges measured to be less than the specified minimum for the drum ends.

No co-relation or pattern could be discerned when comparing the metal thickness to the several performance tests conducted in this program. For example, the best overall drum, code "N", was constructed of one of the lighter weights of steel, though still within specification. Drum code "O", the single submission below specification in steel thickness, did not exhibit unusually poor performance characteristics, and was not one of the drums exhibiting metal fracture during drop testing.

The above data would suggest that metal thickness is not a major factor in drum performance within the limits of the steel thicknesses used in the test drums. Chime geometry and the manufacturing process appear to be the prime controlling factors of drum performance as evaluated in this program.

Both of these factors can be controlled by the drum manufacturers through selection of good chime designs, proper maintenance and adjustment of machinery, and through active product quality assurance programs.

9.6 Drop Tests of 20L Steel Pails

Metal gauges equalled or exceeded the marked gauges.

The percent of closed head pails calculated to be able to pass U.N. recommended regulatory test levels is shown in Table 18.

Code	Pail Type	Drop Orientation	% Probability of Passing: 1.8m	1.2m	0.8m
I	17E (closed head)	Top	31%	99%	100%
		Bottom	58%	92%	99%
G	37A (open head)	Top	0	2%	50%
		Bottom	0	16%	63%
L	37B (closed head)	Top	50%	93%	99%
		Bottom	76%	94%	98%
H	37C (open head)	Top	0	7%	31%
		Bottom	0	31%	57%

TABLE 18

Calculated Percent of 20L Steel Pails Able
To Pass Regulatory Drop Tests
(Rounded to Mearest %)

It is interesting to note that the thinner gauge of 37B pails did not appear to be overly detrimental in terms of resistance to drops compared to 17E pails. However, lighter gauge pails would be more susceptible to denting and piercing (not evaluated in this program). Furthermore, it would appear that the lighter gauge pail will fail more readily under vibration (see A.S.T.M. D4169 data).

9.7 A.S.T.M. D4169 Evaluation of 20L Steel Pails

Closed head pails 17E and 37B were performance evaluated using A.S.T.M. D4169 methods. Neither pail could pass the level 1 or level 2 vibration elements. Both pails were able to pass a full level 3 sequence.

The critical element in this procedure would appear to be the inability of a badly dented pail to survive a vibration test. Typically metal fatigue cracks would develop in association with a metal crease. In this program failures were only observed in the pail bottoms. The inability of these pails to pass a "moderate level" shipping test would appear to be inconsistent with the long use history of these products. It should be noted that the sequence test is not truly representative of the true distribution environment for 20L pails.

Typically, 20L pails are not shipped as individual units, but as parts of a unitized load. Manual handling and incidence of pail denting is greatly reduced in such circumstances. Further, it has been observed that it is usual to remove badly dented pails from stock for marketing and cosmetic reasons. Both of the above would contribute to a more successful actual shipping history than would be apparent from the A.S.T.M. test data. After discussing the possible frequency of pail failures due to vibration induced metal fractures with a number of carriers and warehouse operators, it is the impression of the authors that such failures are practically non-existent.

9.8 Drop Testing of 208L Plastic Drums

The methodology of testing plastic drums is somewhat more complex than for their steel counterparts. A typical plastic drum cannot be gripped for hoisting and dropping as conveniently as a steel drum. A simple and rapid method using non-resilient grips and restraints (see photograph 13) has been criticized as potentially contributing to an earlier failure. It has been proposed that the tension and restraint imposed by such a fixture does not allow the drum to naturally absorb impact shock and that the hard fixtures provide local stress concentration.

A sling method allows a fully unrestrained impact. However, the attachment of the harness and control of drum orientation is more difficult and time consuming. Furthermore, because the slinging method does not provide a positive grip, there is some concern over the safety of the method.

Ontario Research has used both methods and has evolved a reasonably positive and simple fixture (photograph 14). It is felt that the effect of the fixture on the failing drop height is not significant, however, it may be necessary to positively establish this observation.

The wall thickness of plastic drums presents a further problem when trying to observe for leakage. In the experience of ORF technologists, it is possible to develop a significant break at the moment of impact, as witnessed by a substantial spurt of water. However, in the vented rest position, the drum wall thickness coupled with the elastic properties of the plastic can effectively close the fracture, and no immediate leakage will be observed.

There is some justification for including a provision for a slight positive air pressure when inspecting for such leaks.

Photograph 13

Photograph 14

Photographs 13 and 14 - A rigid locking type drum grip (left) and a slinging method (right) that does not impart compressive force on the drum during drop testing.

The calculated ability of the tested drums to meet U.N. and C.T.C. (D.O.T.) requirements are shown in Table 19.

		1.8m	1.2m	0.8m
Top drop	100%	100%	100%	100%
Bottom drop	91%	81%	91%	96%

TABLE 19

Calculated Percent of 208L Plastic Drums Able to Pass Regulatory Drop Tests

9.9 Plastic Pail Lids

It was observed that both submissions of plastic 20L pails leaked past the lid. In both instances, it was said that gasketing material was incorrect and a new submission of both pails and lids was made.

Pails such as the ones evaluated are sometimes marketed with a choice of lid styles. For the purposes of regulating containers, it is importatnt that the correct lid (i.e. the one with which the pail was tested for conformance) be used with the pail. In this regard, it may be useful to have an identifying mark on the lid as well as on the pail body.

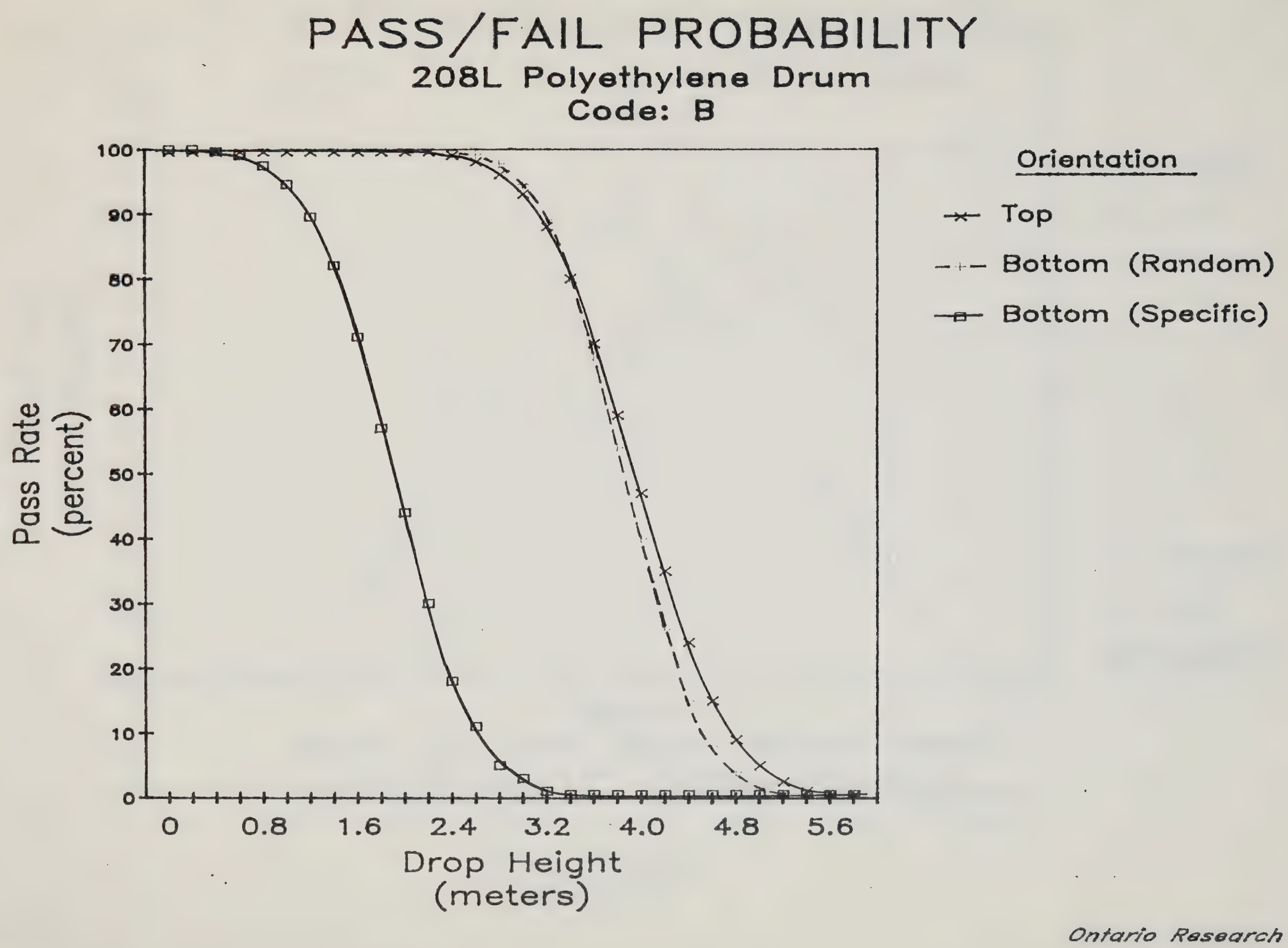
9.10 Pass/Fail Probability Curves

The "staircase" testing method tends to concentrate test levels close to the mean. The Karber method of analysis is designed to determine the mean and to a lesser degree of certainty, the standard deviation. The methods used for collecting and analyzing the data

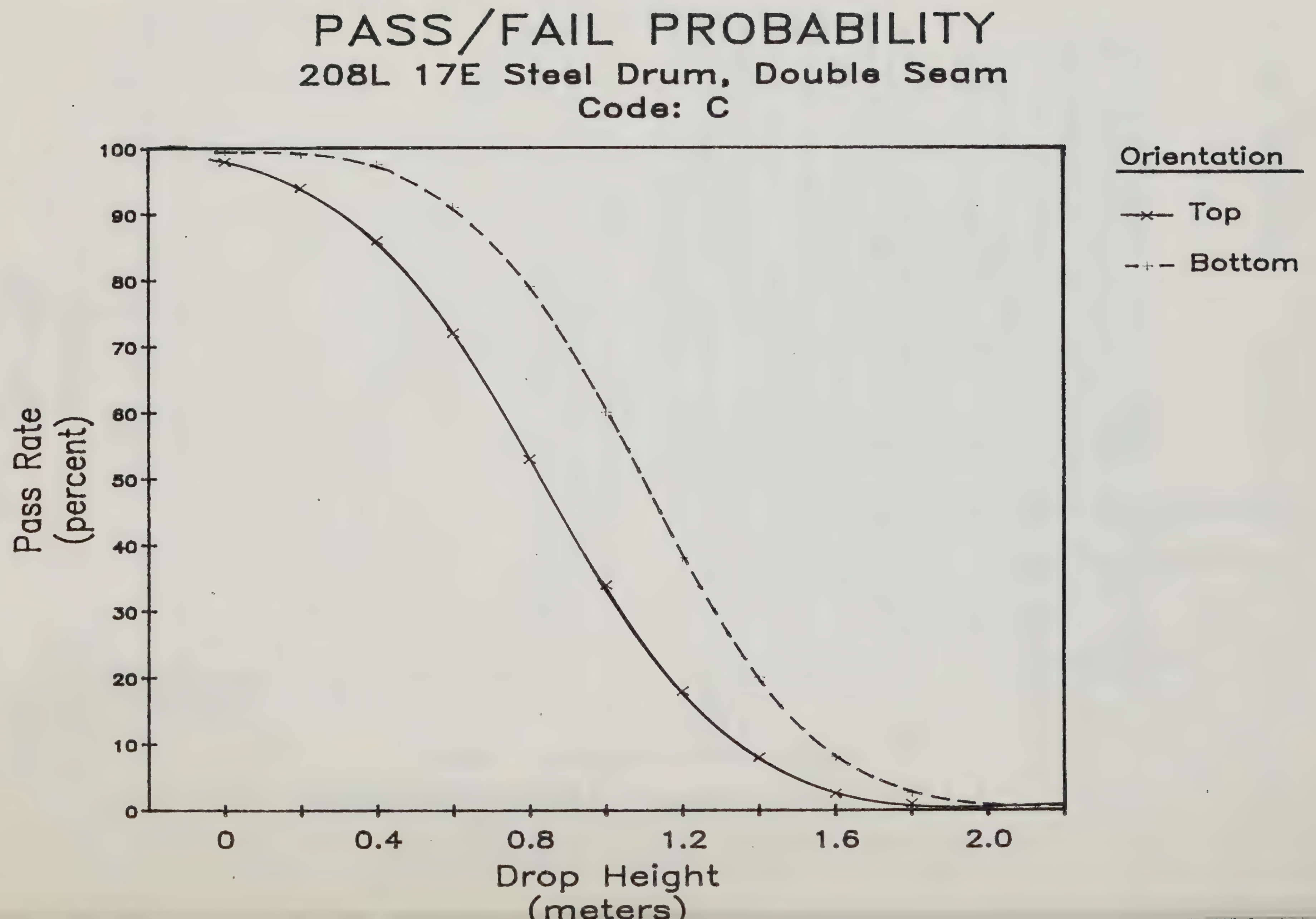
do not provide a great deal of information about the areas at the ends of the distribution curve. The degree of normality for the distribution curves is difficult to determine given the type of data collected. To determine the distribution type with a greater degree of certainty, more containers should be dropped at selected height increments surrounding the mean.

The distribution type has been assumed to be normal in order that a comparison can be made between the different containers. The pass/fail probability curves (pages 71 to 84) were drawn, using the mean and standard deviation values from the Karber analysis. These values were used to create the cumulative normal distribution curves and are intended to show the difference between the top and bottom failure modes, and to allow some approximations to be made about probable failure modes at various test levels.

The pass/fail probability curves are provided as an indicator of the cumulative distribution curve trends for each test set. Additional testing would be required to verify this information.

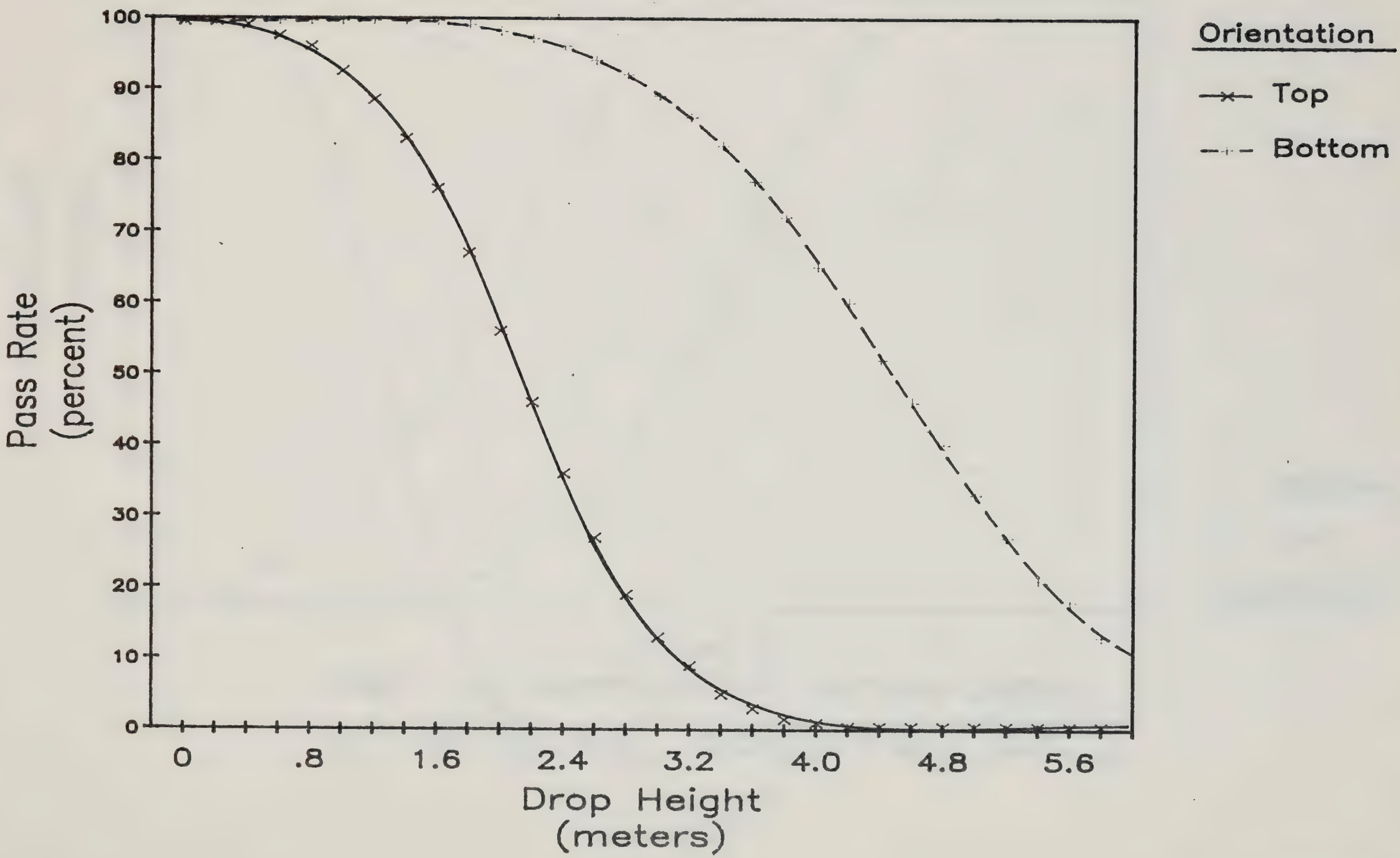


PASS/FAIL PROBABILITY
208L Polyethylene Drum
Code: B
Pass Rate (percent)
100
90
80
70
60
50
40
30
20
10
0
0
0.8
1.6
2.4
3.2
4.0
4.8
5.6
Drop Height (meters)
Orientation
Top
Bottom (Random)
Bottom (Specific)
Ontario Research

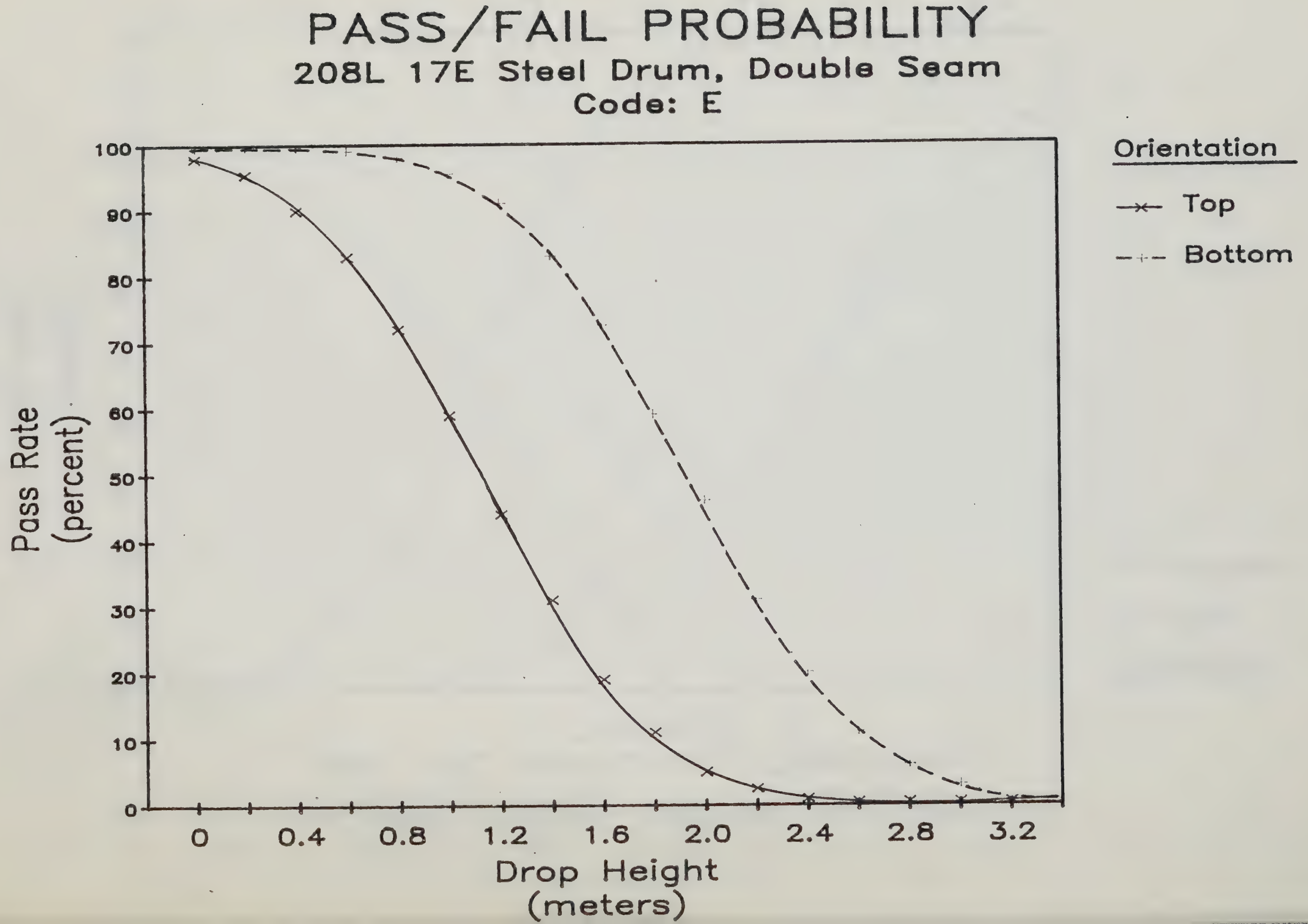

PASS/FAIL PROBABILITY
208L 17E Steel Drum, Double Seam
Code: C
Pass Rate
(percent)
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
Drop Height
(meters)
Orientation
Top
Bottom

PASS/FAIL PROBABILITY

208L 17E Steel Drum, Triple Seam
Code: D

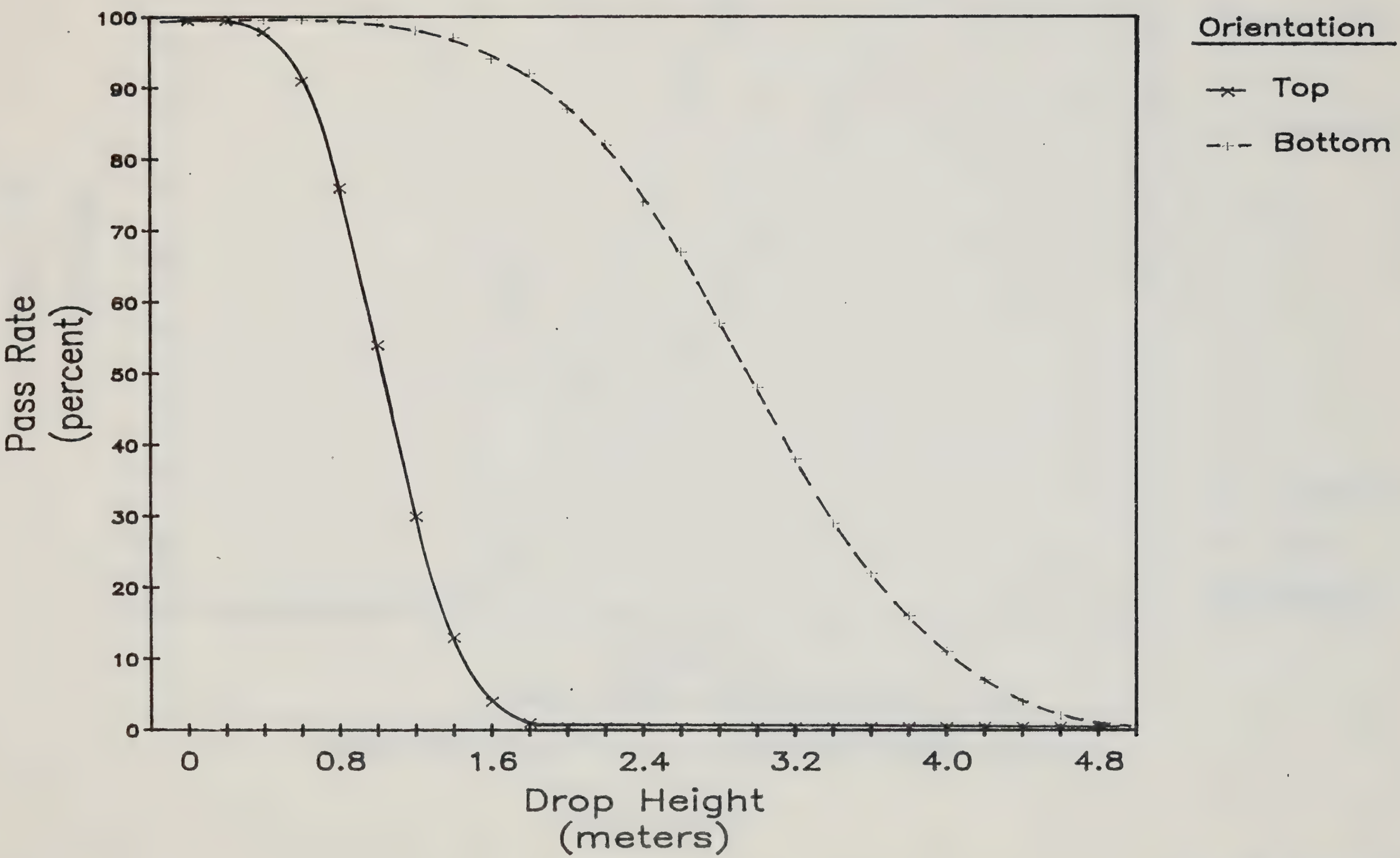


Ontario Research


PASS/FAIL PROBABILITY
208L 17E Steel Drum, Double Seam
Code: E
Pass Rate
(percent)
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
Drop Height
(meters)
Orientation
Top
Bottom

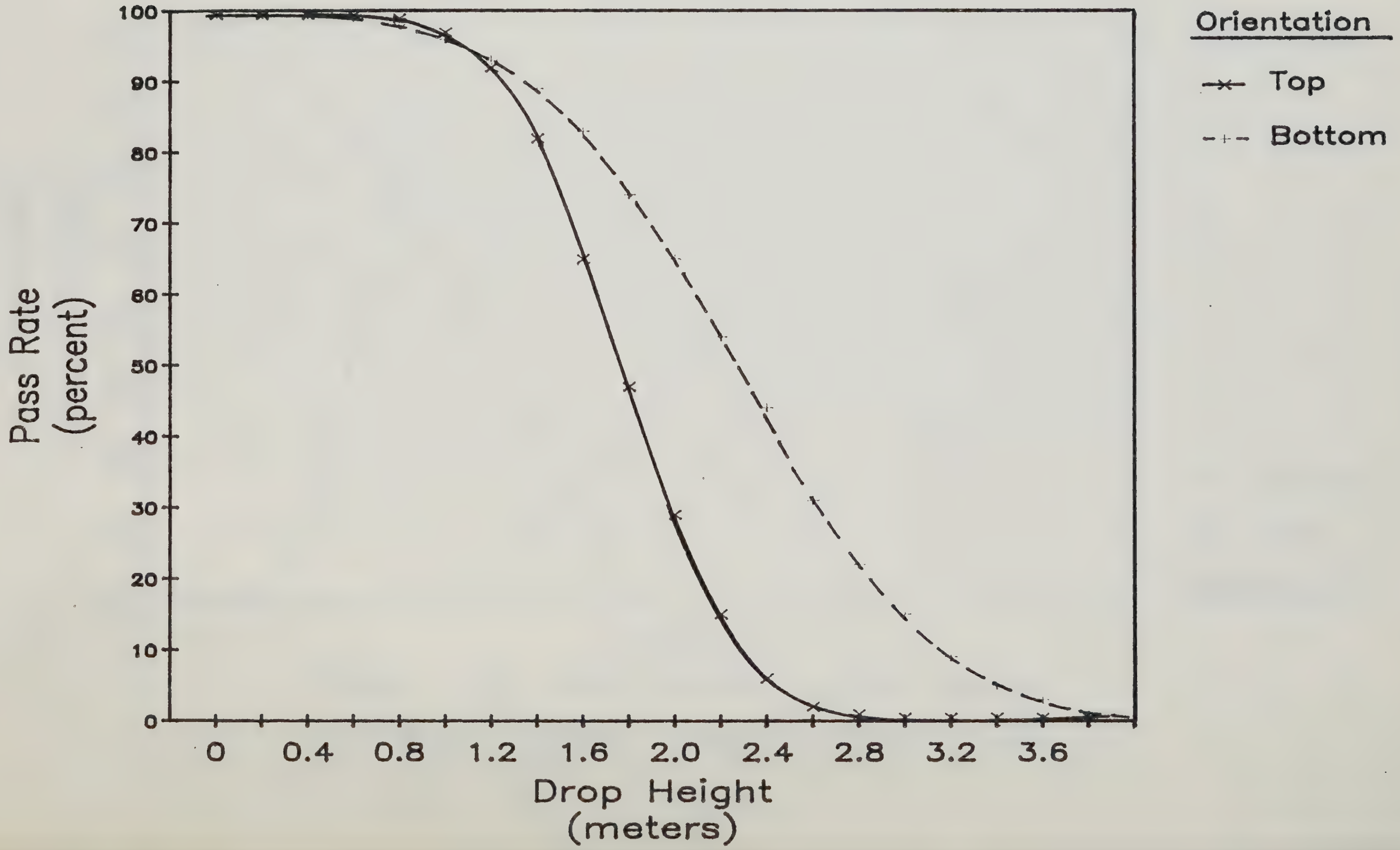
PASS/FAIL PROBABILITY

208L 17E Steel Drum, Triple Seam
Code: F



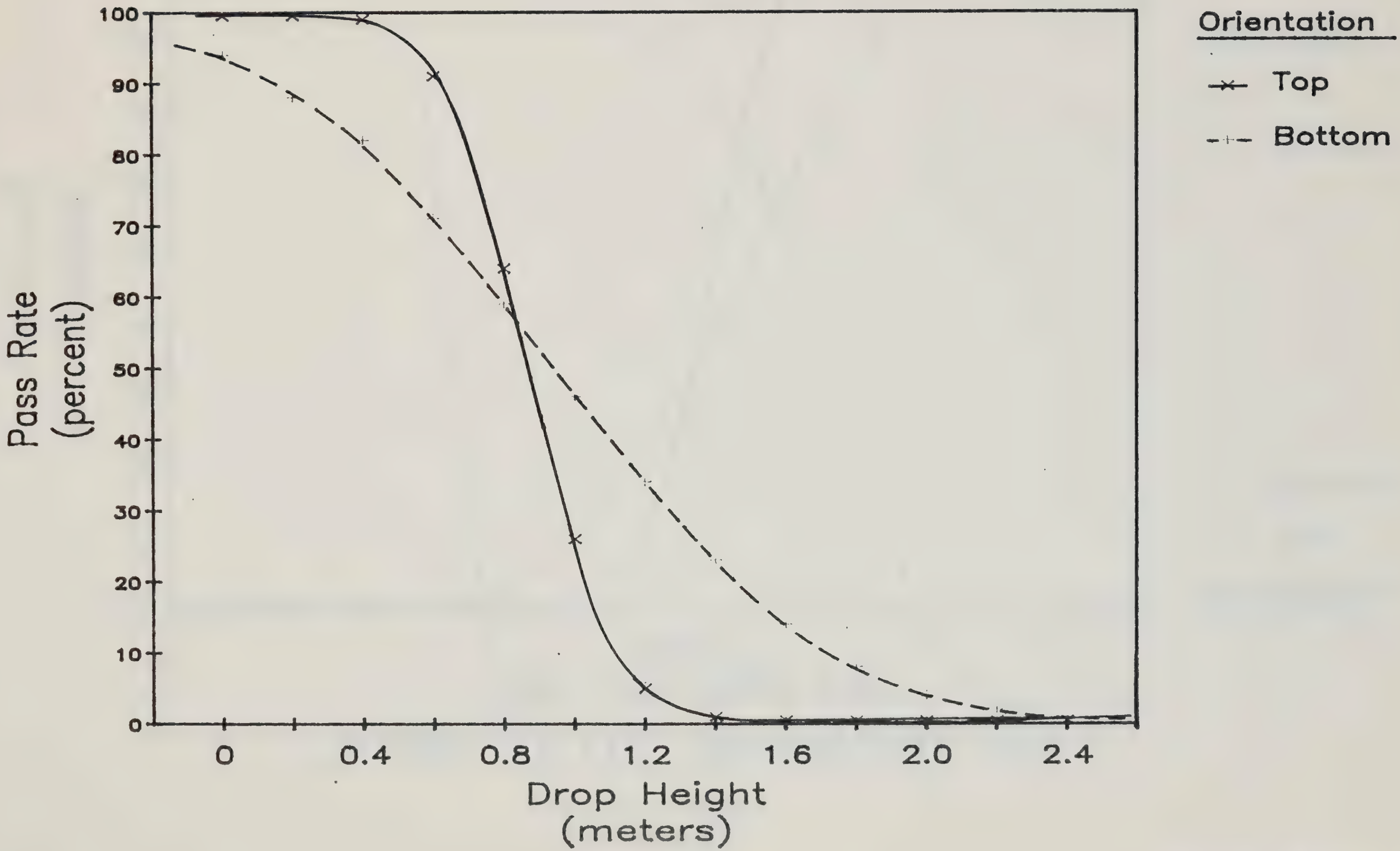
Ontario Research

PASS/FAIL PROBABILITY
20L 37B Steel Pail
Code: G

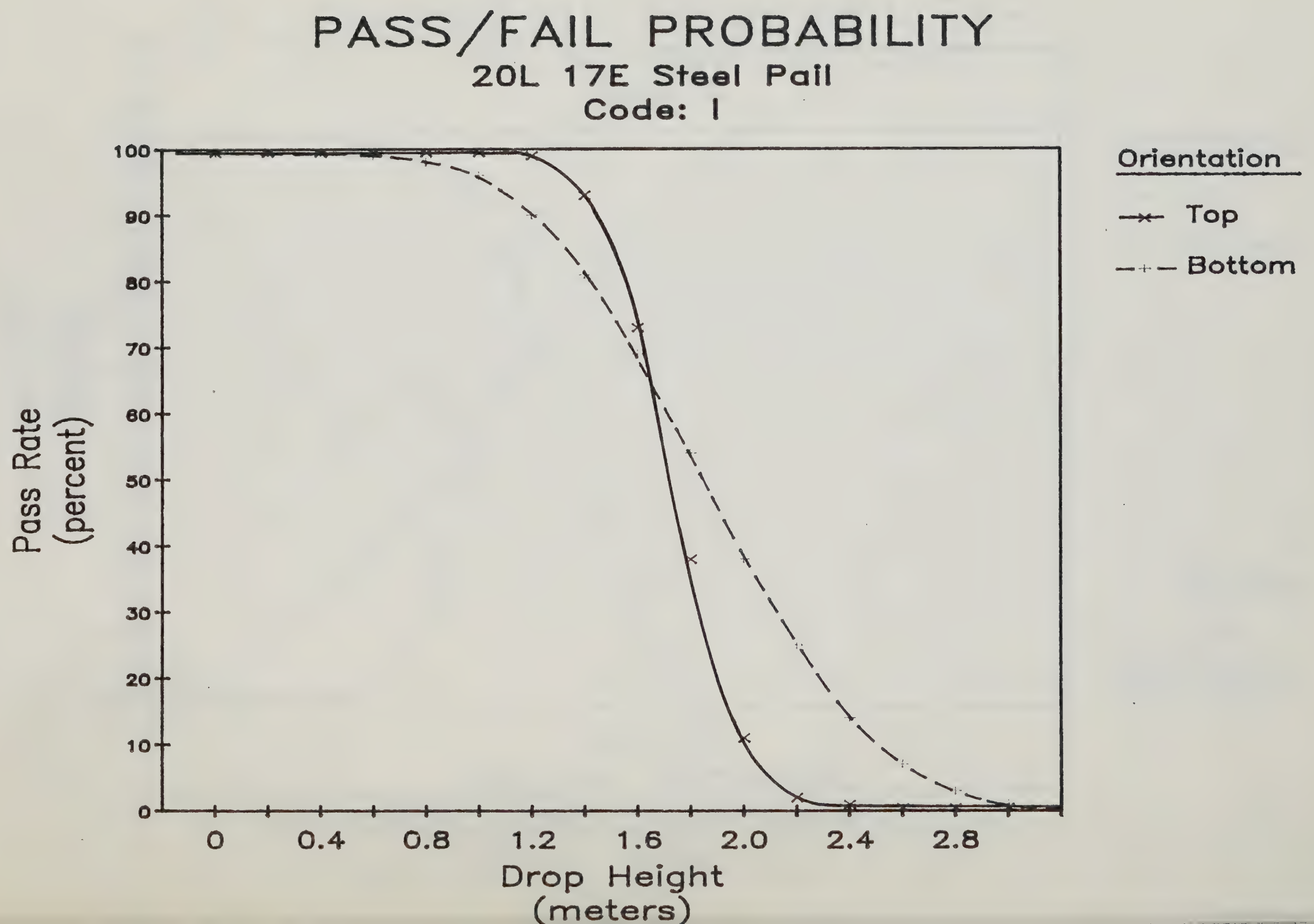


PASS/FAIL PROBABILITY

20L 37C Steel Pail
Code: H

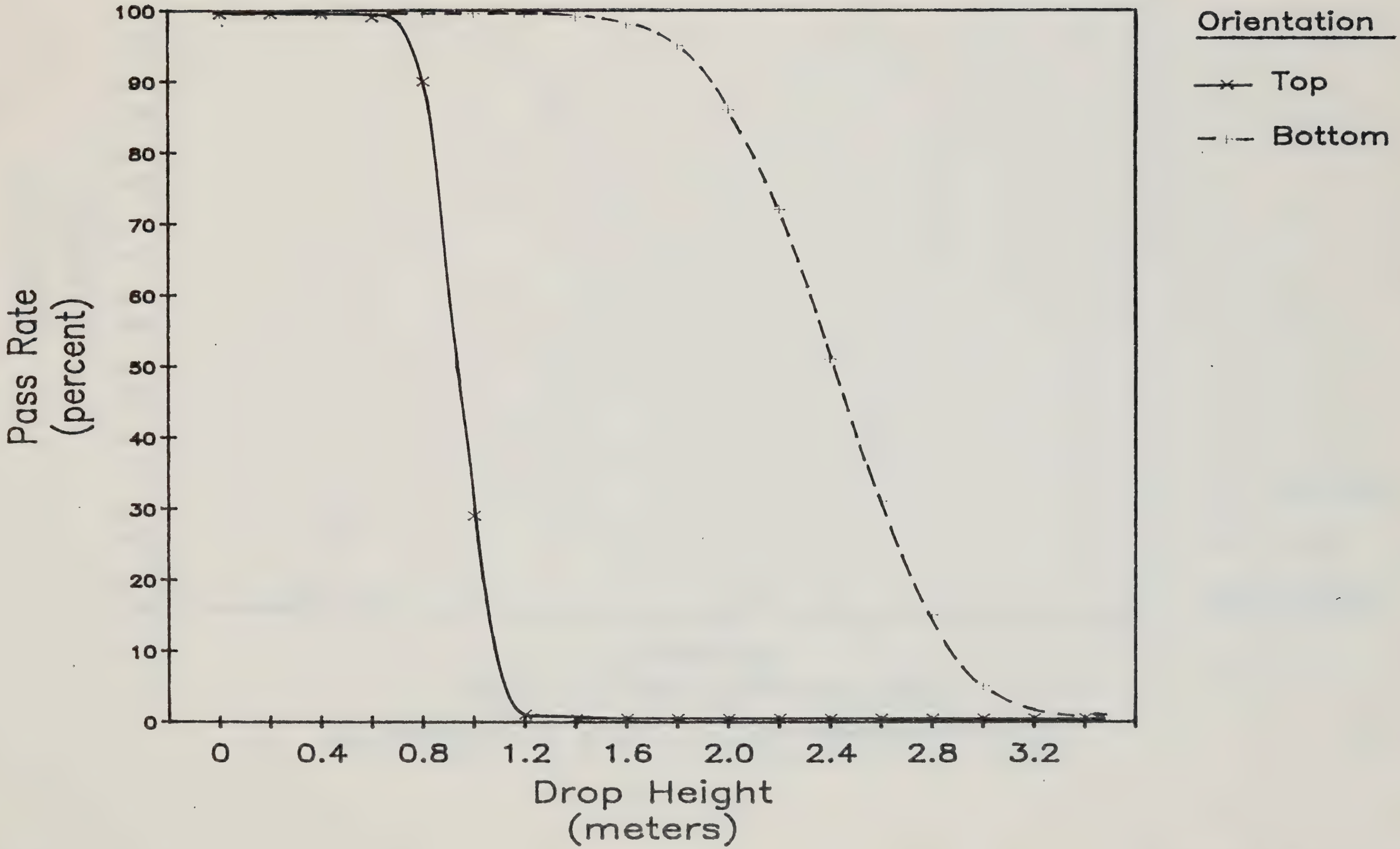


Ontario Research

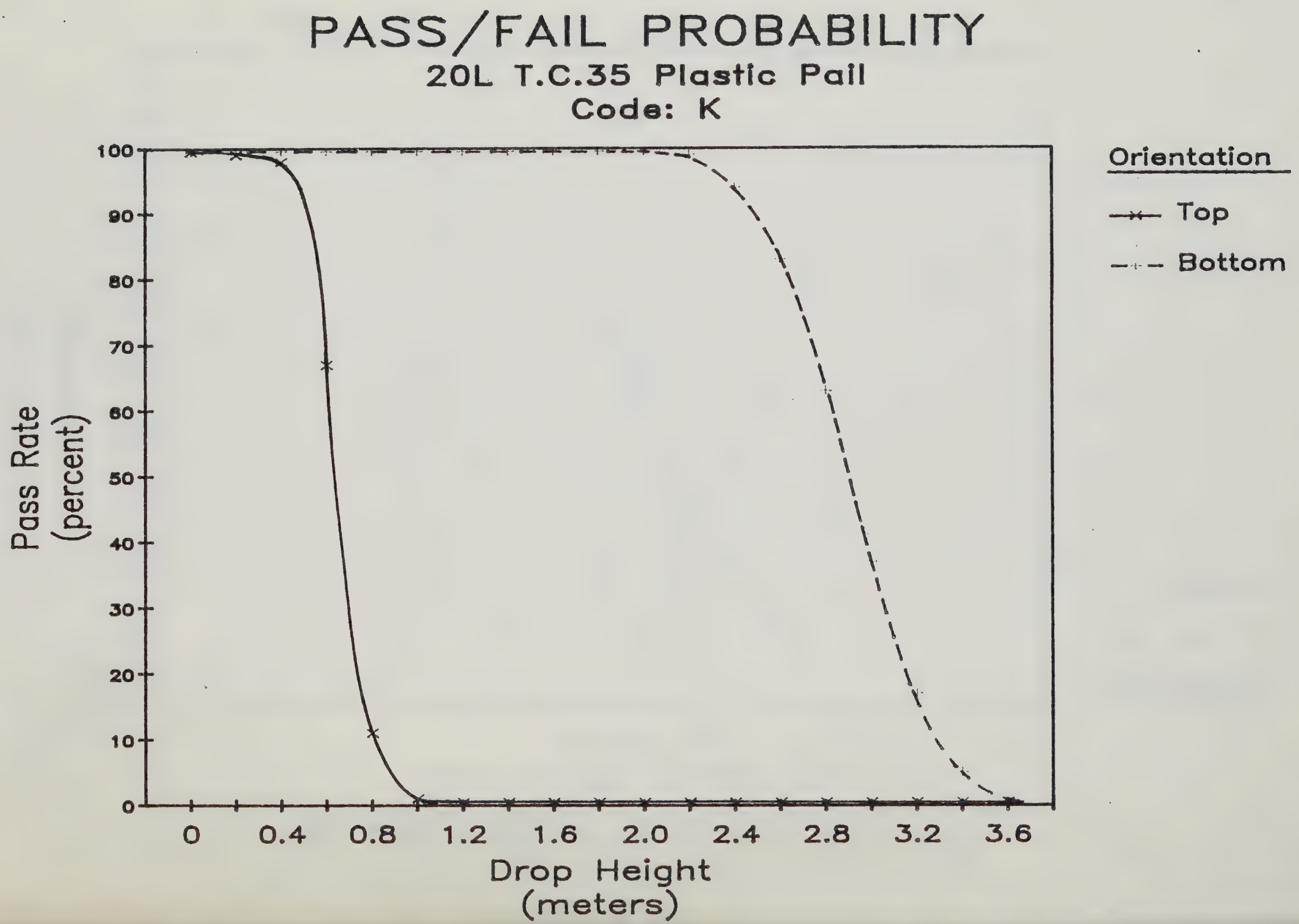

PASS/FAIL PROBABILITY
20L 17E Steel Pail
Code: I
Pass Rate (percent)
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Drop Height (meters)
Orientation
Top
Bottom

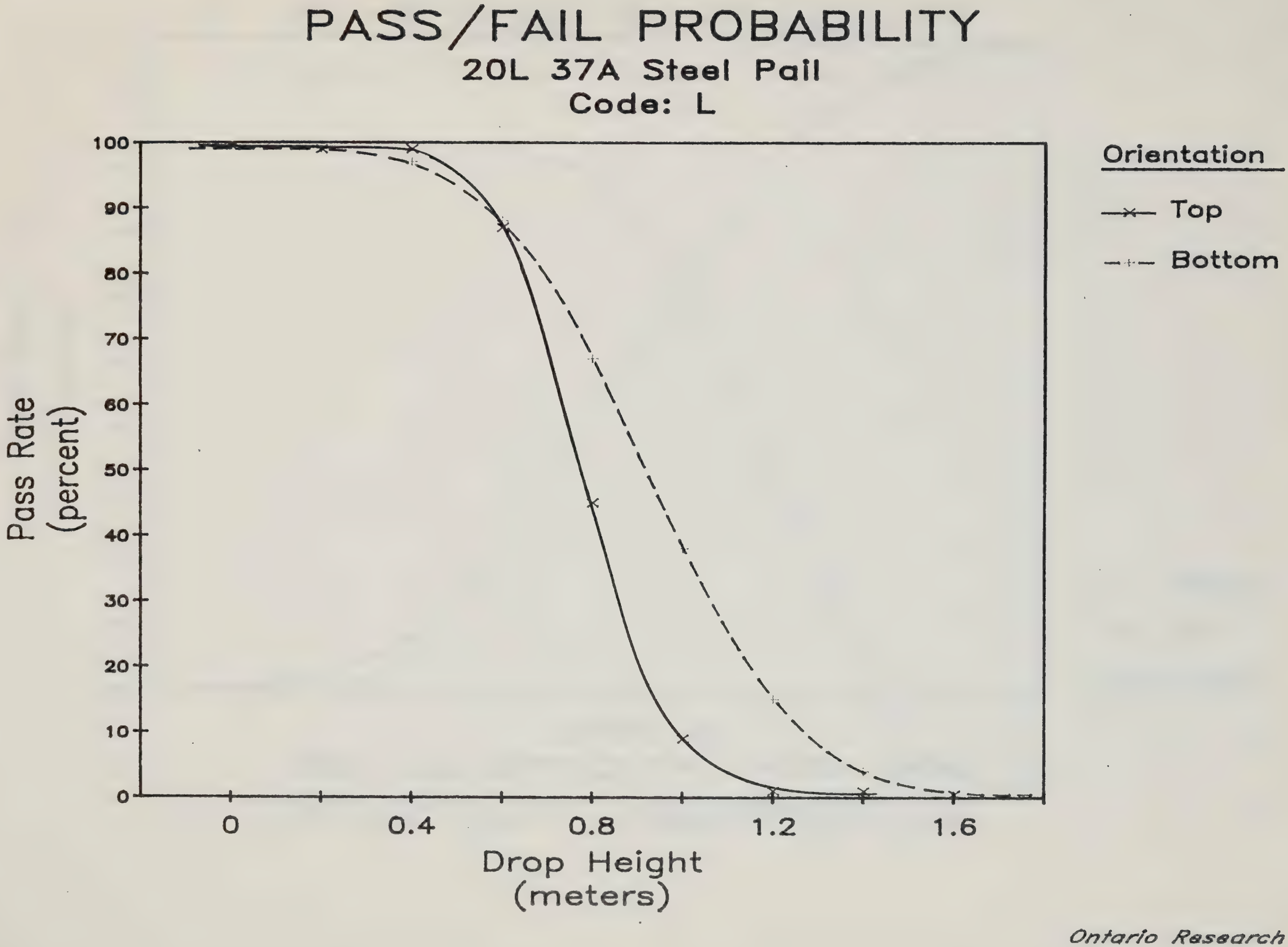
PASS/FAIL PROBABILITY

20L T.C.35 Plastic Pail
Code: J

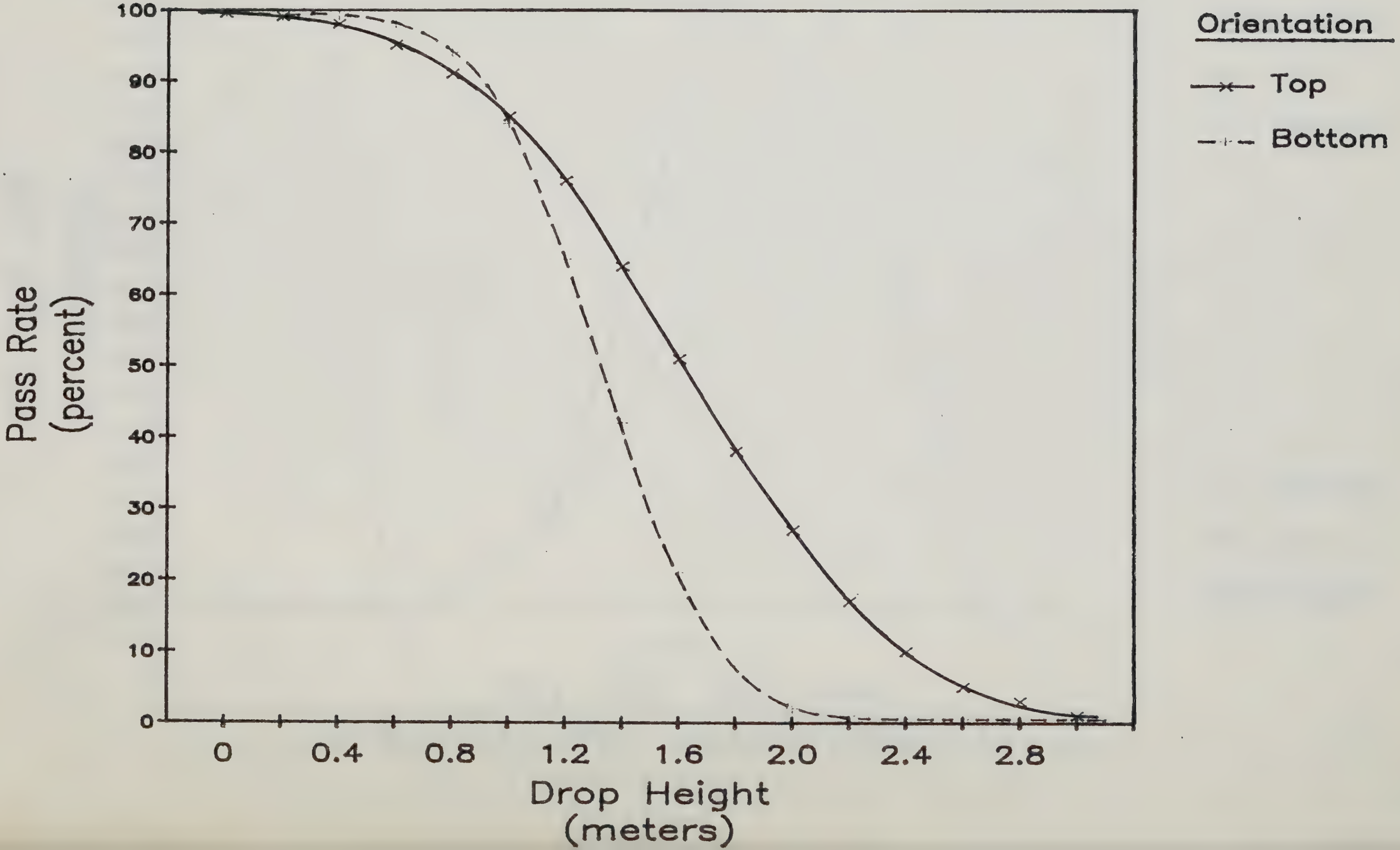


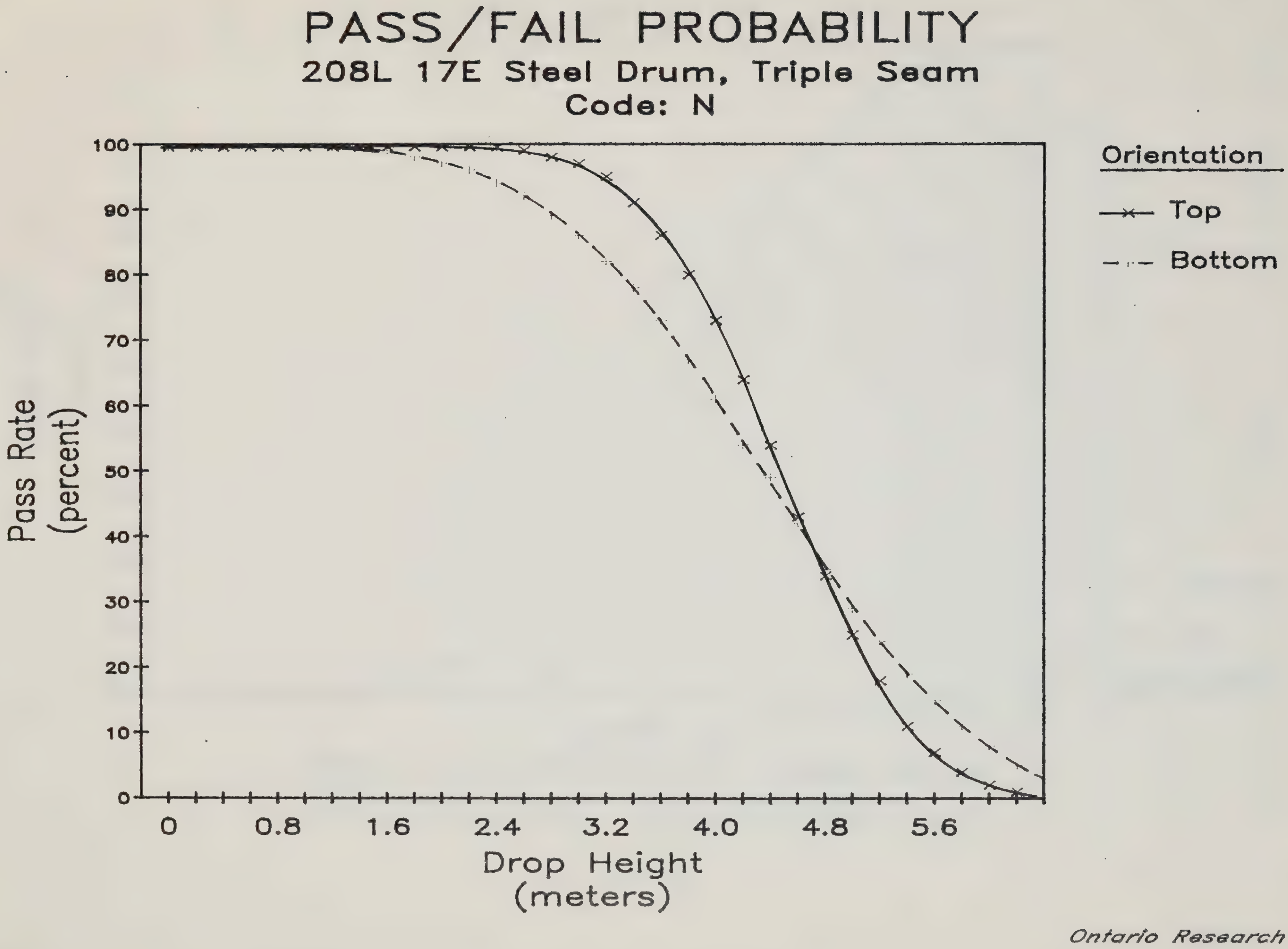
Ontario Research


PASS/FAIL PROBABILITY
20L T.C.35 Plastic Pail
Code: K
Pass Rate (percent)
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
Drop Height (meters)
Orientation
Top
Bottom

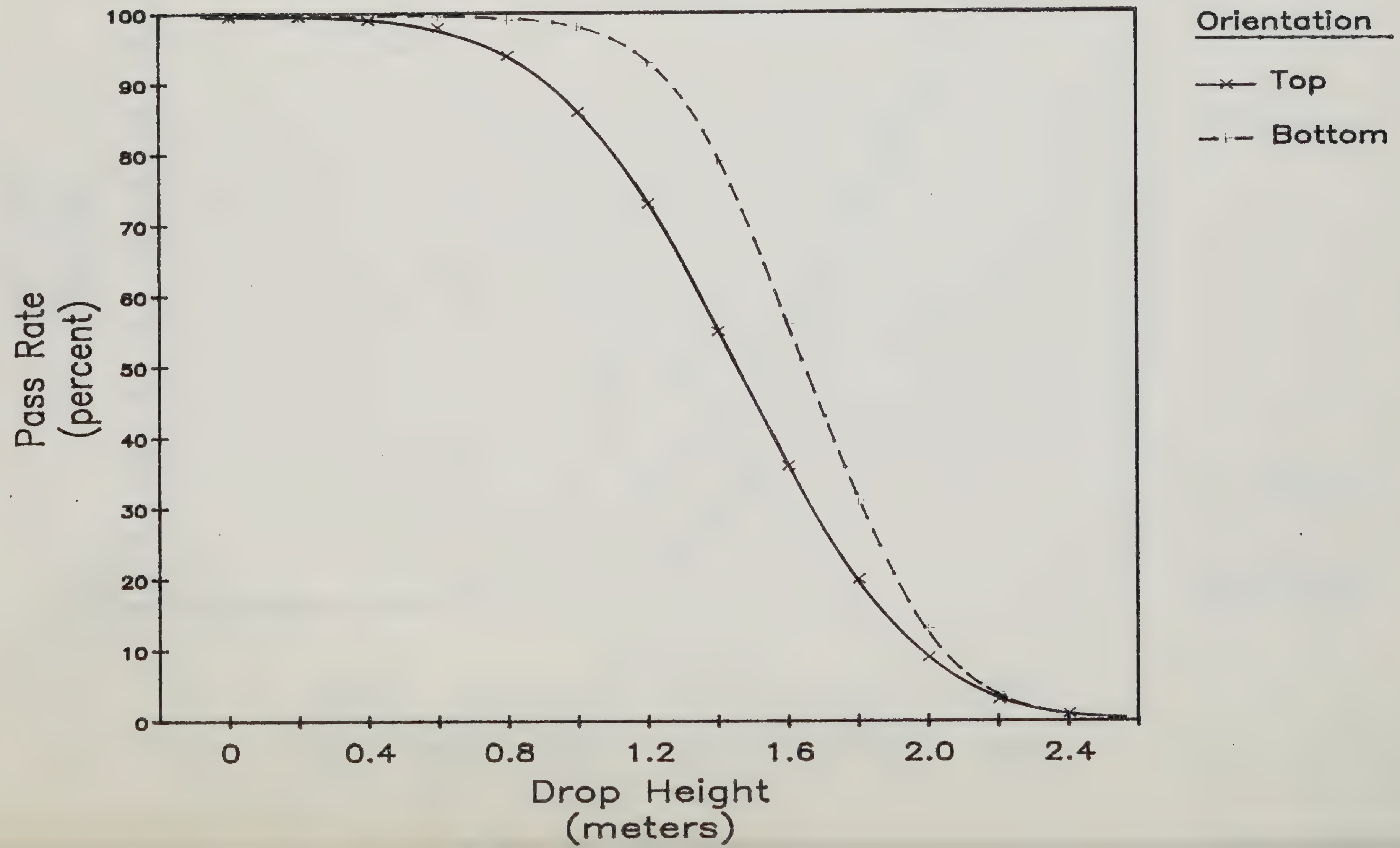

PASS/FAIL PROBABILITY
20L 37A Steel Pail
Code: L
Pass Rate (percent)
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
Drop Height (meters)
Orientation
Top
Bottom
Ontario Research

PASS/FAIL PROBABILITY
208L 17E Steel Drum, Double Seam
Code: M




PASS/FAIL PROBABILITY
208L 17E Steel Drum, Triple Seam
Code: N
Pass Rate
(percent)
100
90
80
70
60
50
40
30
20
10
0
0
0.8
1.6
2.4
3.2
4.0
4.8
5.6
Drop Height
(meters)
Orientation
Top
Bottom
Ontario Research

PASS/FAIL PROBABILITY
208L 17E Steel Drum, Triple Seam
Code: O



9.11 Performance Evaluations and Material Specifications

There has been a marked trend away from standards detailing material and construction requirements to performance type standards. The performance data on steel pails and drums as developed in this program, and the apparently tenuous relationship to metal gauge, would tend to support the validity of the performance approach.

10. FIELD FAILURE OBSERVATION

In June of 1984, ORF became aware of a major drum failure incident:

Forty-two steel 208L 17E drums were filled with 468 lbs. liquid. The drums were loaded onto a truck, single height, and transported a distance of about 1,600 km. It could not be determined whether the drums were on pallets or on the truck floor. It was reported that all forty-two drums had leakages at the destination.

ORF examined a single drum bottom cut from a defective drum and said to be representative of the failures. The drum bottom was of a drop center design and exhibited a small fracture located on the drop center crease line. The fracture had all the appearances of a metal fatigue failure caused by vibration.

ORF was fortunate in obtaining drum samples from the same production batch. Standard and non-standard vibration tests were conducted on these drums in an effort to reproduce the field failure:

Standard	Procedure
N.S.T.A.	One hour at 1.1g and about 4.5 Hz.
ASTM D4169 Vibration	Frequency sweeps from 3 Hz. to 100 Hz. at 0.5g with 15 min. dwells at all resonance points.

The failures could not be reproduced by these standard methods. Additional vibration tests were conducted. Briefly, the drums were exposed to extreme extensions of the standard tests:

- Maintained at resonant condition for 1 1/2 hours.
- Repetitive shock tests for 2 hours.

Again, the failure could not be duplicated.

The inability of standard or extreme vibration performance tests to duplicate an observed field failure is of some concern. Similar vibration tests are required in certain transport regulations and the desireability of a vibration test is a point of discussion between European and North American standards writers.

Pages 88-91 cover a preliminary study of rail shock and vibration, and will be printed in a separate report.

12. SUMMARY DISCUSSION AND FURTHER WORK

The work described in this report indicates that there is a considerable gap between the actual performance of selected containers, and the performance required by regulatory bodies. Assuming that the actual field performance of the containers tested (as evidenced by their successful use in the field) is acceptable, then there is reason to question the performance levels required by regulatory bodies. Conversely, if we assume that regulatory performance levels are correct, then there is a substantial upgrading in performance levels required to be undertaken by industry.

The question of whether a 1.2m drop test (for example) is an appropriate test at an appropriate level for regulation purposes, was not addressed in this program. However, it has been pointed out that the commonly used pass/fail drop test does not recognize the statistical reality of such events, and that the number of samples currently required for a test procedure is not statistically significant. The adaption of an ongoing staircase program, both as a quality control method and as a means of assuring conformance with regulations, has much to recommend it, and should be further examined, along with means of assuring statistically valid sampling levels.

Conceptually, A.S.T.M. method D4169 is very attractive. However, based on our experience, adapting the methodology, for regulatory purposes, would be premature. The three principle problems with this method are:

- It is a very time consuming method requiring sophisticated and expensive equipment. It would not be suitable as a quality control tool.

- The performance of individual elements in the test cycle are still open to interpretation. Different laboratories would undoubtedly introduce small but significant variations into the test procedure.

- The relationship between certain elements (e.g. rail shunting and vibration) and the actual distribution environment, is not clear.

Simulated rail shunt tests appear to be too severe, as specified by A.S.T.M. D4169. It is recommnded that a program to provide a definite co-relation between simulated rail shunting tests and a real car shunt be undertaken. The objective of this program would be to provide a simulated rail shunt test that would exactly duplicate the damage observed in an actual shunt.

There is currently a divided opinion on whether a vibration test is necessary for regulated containers. Discussions with distribution agencies suggests that failures due to vibration almost never occur.

There is, however, a second opinion that vibration failures do occur in significant numbers, but that they are not reported or recognized as such.

Standard vibration tests were not able to duplicate the single failure (208L steel drum) documented by ORF as apparently due to vibration. At the same time, conventional 20L pails, successfully used in large numbers, are not able to pass the vibration elements of a level 2 A.S.T.M. D4169 performance test. There would appear to be some serious contradictions.

The application of and the co-relation of vibration tests with field data needs to be investigated. The objective of this program would

be to develop a methodology that would be able to duplicate in the laboratory, failures observed in the field. Such a program would be best carried out with containers known to have vibration failure problems in the field.

Steel drums and pails have been a major emphasis in this program. However, since the commencement of this project, there has been a major and dramatic shift to plastic containers. Plastic drums and pails have made major inroads into the petrochemical industry. Many agricultural chemicals have converted from delivery in 20L steel pails to plastic containers, most notably to pairs of 10L jugs enclosed in corrugate fibreboard boxes.

Plastic containers have many advantages over steel. There are also a greater number of inherent problems associated with the use of plastic. These range from chemical compatibility, closure efficiency, and control of variables to produce a consistent container, and permeability. In the instance of test protocols, we have noted the difficulty in achieving an acceptable drum drop test methodology and interpretation. It should also be noted that of all tests conducted, only the 208L plastic drum had a marked orientation sensitivity during test.

It is recommended that further performance studies be conducted with plastic containers of all types. The objective would be to better establish test methodologies as applied to plastic containers and to establish performance profiles, similar to what has been done for 208L steel drums. Important aspects, not addressed in this report, would be performance at reduced temperatures, the long term stacking properties, permeabilities, and stress crack properties of plastic containers.

Another trend concerning plastics that is not addressed in the dangerous goods regulations, is the increasing use of shrink wrapped trays to replace corrugate containers. The acceptability of such packagings for dangerous goods should be investigated. (Ontario Research has had recent enquiries addressing this subject).

A fundamental problem, related to almost all aspects of this program, is the lack of specific information describing the nature, quantity and mechanism of actual container failures experienced in the field. The inability of standard vibration tests to be related to field data and the uncertainty of the simulated rail impact tests are two examples. As a further example, data developed in this program, indicates that light gauge metal containers can be made to pass current required tests. However, this does not address the problem of container puncturing, that has been observed in the field by this report's author.

A major study of field failures is recommended to establish the nature, frequency and mechanism of field failures. This program should look to collecting samples of containers demonstrated as having problems in distribution, and then establish a laboratory procedure that quantifies basic container threshold values, or establishes a clearly co-related test method for assessing a particular performance characteristic. The relevance of all historical test methods to current distribution methods, container types, and materials should be substantiated.